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IN

# SCIENCE

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# CONSTABLE'S

# ORIENTAL MISCELLANY

OF

ORIGINAL AND SELECTED PUBLICATIONS

VOL. II

# POPULAR READINGS

IN

# SCIENCE

Westminster

ARCHIBALD CONSTABLE AND COMPANY

14 PARLIAMENT STREET S·W

MDCCCXCII

# POPULAR READINGS

IN

# SCIENCE

BY

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# INTRODUCTION

# INTRODUCTION

IN compiling this volume of CONSTABLE'S ORIENTAL MISCELLANY, we have sought to introduce such matter as might form the basis of a general course of instruction in Science, suited to the requirements of the pupils in Indian schools who are preparing for matriculation at the University. The volume is also intended to meet the wants of those who leave school before matriculating, and of whose education some knowledge of Science would form a useful and desirable part. We believe that some of the more recent and interesting results of scientific research will not only prove instructive and highly interesting to those who may not have had access to them, but that they ought to be included in every collection of scientific facts—forming as they do what has been aptly called the romance of Science.

As the plan best fitted for securing the foregoing objects, the narrative form has been adopted in the preparation of the volume. This, as its title implies, gives it the character of a reading-book, which may be used in the higher classes of Indian schools, and one which best adapts itself to the taste of the general reader.

With the object of inducing readers to interest themselves in Scientific studies, and of awakening enthusiasm

for the pursuit of that branch of Science which each may find suited to his tastes, prominence has been given to the results which have been arrived at in the course of Scientific discovery rather than to the methods by which the results have been reached. At the same time due care has been taken to give, where necessary, such explanations of elementary principles as will enable the reader to obtain a general grasp of the subjects under consideration.

It is generally admitted that some knowledge of Science ought to form part of a liberal education, and that Science teaching does not in general form part of a *School* course in India may in some measure be due to the want of a suitable introductory manual dealing with science. It is hoped that the present volume will be found useful in supplying this want.

Sir Auckland Colvin, Chancellor of the Allahabad University, in his address before Convocation on the 20th January last, when referring to the educational value of a scientific training for Indian students, quotes from one of Sir H. Maine's addresses to the University of Calcutta, a passage which we here take the liberty of reproducing. 'The fact is, that the educated native mind requires hardening. That culture of the imagination, that tenderness for it, which may be necessary in the West, is out of place here; for this is a society in which for centuries upon centuries the imagination has run riot; and much of the intellectual weakness and moral evil which afflict it to this moment may be traced to imagination having so long usurped the place of reason. What the native mind requires is stricter *criteria* of truth; and I look for the happiest moral and intellectual results from an increased devotion to those sciences by

which no tests of truth are accepted, except the most rigid.'

Sir Auckland Colvin, while accepting this view of the case, goes on to observe in his own words: 'The objection may possibly be taken that, while all this may be perfectly true, sufficient means of instruction in Physical Science are at present, as a matter of fact, wanting in the schools which prepare students for entrance to the University. The objection is not without weight; and if the University shares this opinion, it will probably cause its views to be laid before the Administration, in order that such remedial measures as are possible may be introduced.' These words, coming as they do from so high an authority, indicate the desire on the part of the Government to further in every way possible the introduction of the teaching of Science into the Schools of the country.

A few words with regard to the contents of the volume may not be out of place here. We lay no claim to originality, but in the selection of materials have endeavoured as far as possible to introduce, for explanation and illustration, subjects which are of fundamental importance in Science; and would here refer more particularly to the sections which treat of Evolution, Energy, and the Spectroscope.

The Darwinian theory has assumed so great importance, and has exercised such a far-reaching influence on the study of biology of late years, that in our opinion some account of this theory ought to form part of every miscellaneous collection professing to give even the barest outline of recent scientific results. In our epitome we have followed Professor Patrick Geddes. We have also introduced a short account of the recent speculations in

Chemistry, with special reference to the opinions of Crookes and others in regard to the compound nature of the elements, and have besides given a table of the natural arrangement of the elements, and stated briefly some of the conclusions arrived at from this remarkable and beautiful development in Chemical Science. Some account has also been given of Tidal Evolution, which Professor G. H. Darwin of Cambridge has so successfully applied to the interpretation of the history of our earth-moon system. For this account we are indebted to the writings of Sir Robert S. Ball, the Royal Astronomer of Ireland, and the account of the Nebular Theory of Laplace is also due to the same source. The history of our earth-moon system is most fascinating, and the astounding conclusions which follow from the application of the dynamical principles necessary for the proper interpretation of the past and future history of the earth-moon system, cannot fail to excite the keenest interest even in minds little prone to indulge in flights of imagination. It must be borne in mind that the history of our earth-moon system is no mere speculation, but a real history founded on principles which are as true as the mathematical reasoning upon which it is based. The vast interest inseparably connected with this subject must be our excuse for having given a brief outline in a popular form of the subject so ably treated by Sir R. S. Ball in his *Time and Tide.*

Among the scientific advances of the present day the establishment of the great principle of the Conservation of Energy must be regarded as only second in importance to the evolutionary movement. Sir H. Davy and Count Rumford had to some extent paved the way for this generalisation by showing that heat is a species of motion; but the general recognition of the principle dates from the period

of Dr. Joule's determination of the mechanical equivalent of heat. As time went on it gradually became clear to physical thinkers that the different forms of energy are interchangeable, and that there exists between them an exact numerical equivalence. The principle was originally known under the name of the *persistence of force,* and Grove wrote a treatise, entitled *The Correlation of the Physical Forces,* in which he showed the existence of certain relations between the different forms of energy. As soon as the distinction between force and energy was more fully realised, the term 'Conservation of Energy' took the place of the former erroneous designation. By the subsequent labours of Clausius, Rankine, Helmholtz, Mayer, Clerk Maxwell, Sir W. Thomson, Tait, and Balfour Stewart, the doctrine has assumed its modern form, *that every species of energy can be converted into every other, and that the sum of all the energies kinetic and potential is constant throughout the universe.* This all-pervading principle has in many ways modified and changed our conceptions of physical phenomena. It affects and controls our notions with regard to the sun's heat, the orbits of planets, the nature of meteors; and guided by its clear and certain light men have been able to gain some insight into the past, present, and future of the universe.

The invention of the spectroscope and the discovery of the method of spectrum analysis mark another important advance in Physical Science. For, to say nothing of its numerous other applications, the spectroscope shows that the same ultimate materials exist in the sun, the stars, the earth, the planets, the comets, and the nebulae. By means of the telescope astronomers had been able to discover the existence of spots on the surface of the sun, and Newton's researches had fixed his place as the central attracting

body in our system, but until this new method of research had come into use nothing was known regarding his constitution. As the result of the observations and investigations which have been carried on by means of the spectroscope, the condition of the exterior surface of our luminary has been pretty accurately ascertained, and many of the elements which enter into his composition have been recognised.[1]

A very short account of the vegetable kingdom has also been given, and in view of the interest attaching to the researches of Pasteur, Koch, and others, some account of the lower forms of fungi named bacteria have also been introduced. For this latter the facts have been obtained from *Chambers's Encyclopaedia.*

It is hoped that the sections which deal with weather and atmospheric phenomena will prove useful to Indian students. In treating this subject, the method we have adopted has been to explain or state the underlying principles, and afterwards to illustrate them by reference to the statistics of the various observations bearing upon the point at issue. For these latter, so far as India is concerned, we are wholly indebted to Mr. Blanford's valuable work on the *Climates and Weather of India.* Mr. R. H. Scott's Elementary Meteorology has also been consulted. Apart from their bearing on weather, the movements of the atmosphere may be regarded from a physical point of view as the effect due to radiant solar energy.

The articles on Gases, Water, etc. contain a pretty full account of all that can be stated concerning their properties without the use of the higher mathematics. Several

[1] For the articles on Energy and the Spectroscope we have consulted chiefly the writings of Professors Tait, Balfour Stewart, Roscoe, and Newcomb.

numerical typical examples have been worked out with the view of enabling the reader to understand more clearly the experimental results.

With regard to Light, we have to observe that our object being to illustrate some of its effects, reflection and refraction have only been treated in so far as they are required for a clearer understanding of the remaining portion of the article.

Experience acquired in teaching Physical Science in India has guided us in the choice and treatment of the subjects contained in this volume; and we trust that the contents will prove both instructive and interesting to the different classes of readers for whom the work is intended.

J. G.
D. R.

EDINBURGH, *July* 3,
1891.

# METEOROLOGICAL PHENOMENA

# METEOROLOGICAL PHENOMENA

THE subject of Meteorology includes a very wide range of phenomena, many of them being of a very complicated character. Accordingly in the present chapter, which deals with the atmosphere, nothing is aimed at beyond the explanation and illustration of some of the more important principles which lie at the foundation of meteorological science, and no attempt has been made to deal either exhaustively or systematically with such a large and important subject. Meteorology treats of the action of those forces which produce changes in the temperature, pressure, humidity, and electric condition of the atmosphere. The atmosphere is the name given to the gaseous envelope which surrounds the earth. Its arrangement is such with respect to the earth that its upper surface is supposed to have the same form, and to be concentric with the earth. Atmospheric air consists essentially of two gases, Oxygen and Nitrogen. They are not chemically combined, but form a mechanical mixture in the following proportions :—

| By volume. | By weight. | |
|---|---|---|
| Oxygen 20·9, . . . . | 23·9 | In 100 parts. |
| Nitrogen 79·1, . . . . | 76·9 | |

In addition to the two gases above mentioned, the atmosphere contains a small quantity of carbonic acid and some aqueous vapour. From a meteorological point of view this last constituent is of very great importance. The atmosphere, being gaseous, obeys the same laws as gases under varying conditions of pressure and temperature, and as it consists of matter it is subject to the action of gravity

and consequently possesses weight. It gradually decreases in density as we ascend, and if it possessed throughout the same density as it has at the surface of the earth, its height as measured by the barometer would extend to about five miles. There is reason to believe that its extreme height does not exceed forty-five miles. The highest elevation reached in a balloon is about seven miles, and at this height the air is so rarefied that great difficulty is experienced in breathing. *Weather* is the state of the air at any time as regards heat, moisture, wind, rain, clouds, and electricity, and that which we call good or bad weather depends upon the aërial movements which result from variations in one or more of the above-mentioned conditions.

A principle of fundamental importance in dealing with the phenomena of the atmosphere is that air will flow from a region of high pressure to one of low pressure. This enables us to ascertain the direction of the prevailing winds at any place; and from a knowledge of this fact we can judge whether the air is likely to be dry or moist, of high or low temperature—two things which are of great importance in judging of the climate of a place. The same principle enables us to trace the course of storms and to explain generally all changes of weather.

The observation of temperature is one of the first points which require attention in meteorology. The instrument used for ascertaining temperatures is the thermometer. Of these, various types are in use—ordinary thermometers, maximum thermometers, minimum thermometers, and solar radiation thermometers. The three last types are known as self-registering thermometers. They are ordinary thermometers provided with a contrivance which enables them to show the highest or lowest temperatures to which they have been exposed during a given interval of time. These thermometers are generally read once a day, and then set so as to agree with the temperature at the time. The mean temperature of any day is obtained by taking the average of the maximum and minimum

temperatures for the twenty-four hours. When the mean temperature of a day has been calculated, the values thus obtained are combined so as to obtain the means for longer periods. The average of the daily means for one month gives the monthly mean, and for the mean temperature of the year, meteorologists have agreed to take the average of the twelve monthly and not the average of the three hundred and sixty-five daily means. The monthly and annual averages are next combined in periods of five years, the periods being so chosen that the year with which they end is a multiple of five. In this manner the mean temperature of the place is obtained. It should be noticed that two places which have the same annual mean temperature do not necessarily agree in climate, since there may be a great difference between the temperatures of the hottest and coldest months at the two places. To understand how changes of temperature are brought about at any place on the earth's surface, we have to remember that the sun is the source of the heat which comes to the earth, and that the heating effect of the sun on the earth is not uniform, owing (1) to the rotation of the earth on its axis, which is the cause of day and night; (2) to the yearly motion of the earth in its orbit round the sun, combined with the inclination of the earth's axis to the ecliptic.

The amount of heat received from the sun gradually increases from sunrise till noon, and then decreases till sunset, while during the night no heat is received from the sun. The earth during this time is giving out heat by radiation, but from sunrise till noon the earth receives a somewhat greater quantity of heat than it radiates, so that the maximum of heat is not reached till about two P.M., which is the hottest part of the day. In fine weather the diurnal change of temperature is very regular in India. The air is coolest a few minutes before sunrise. After sunrise the temperature increases very rapidly up to eight o'clock. From this hour it continues to rise more slowly, and reaches its highest point about two P.M. The

daily range of temperature depends greatly on the dryness of the air and the clearness of the sky. It is greater in North-Western India than in the neighbourhood of the sea. It is also greater in the dry spring months than during the rainy season. In the dry tract of country to the west of the Jumna the daily range of the thermometer is greatest in October and November, and averages from 35° to 40°. In Behar and the North-West Provinces it averages about 30° during March and April. These daily variations of temperature in India are much greater than those which take place in Europe, and constitute an important factor in the climate. In England the range varies from 10° to 20° in the summer, when it is highest. At hill-stations in India the range varies according to the position of the place. At Simla, Mussoorie, and other Himalayan stations situated on a ridge it is less than on the plains. The position, however, has the effect of increasing the daily range if, like Quetta, the place is situated on a high table-land, or in a deep valley, like Leh. At the Himalayan Sanitaria the daily range of temperature approximates to that of the south of England in summer, but is greatest in winter; while in England it is least at that season.

It is the yearly motion of the earth round the sun, or, what amounts to the same thing, the apparent yearly motion of the sun round the earth, that has most influence in bringing about meteorological changes, since to this cause we owe the changes of the seasons. Twice every year, at the equinoxes, the sun is vertical over the equator. At those times every place on the earth's surface, from the north to the south poles, has a day and night consisting of twelve hours each. From the vernal equinox, March 21st, to the autumnal on September 21st the sun is north of the equator, and during these months the northern hemisphere receives more heat than the southern, and in consequence of this, places north of the equator will show a higher temperature than those in the southern hemisphere.

From the autumnal equinox on 21st September to the 21st March, the sun is south of the equator, and since the northern hemisphere will now receive less heat than the southern, the recorded temperatures will be lower. The apparent path thus described by the sun during the year is a great circle, whose plane is inclined at an angle of about $23\frac{1}{2}°$ to the plane of the equator. All places situated on the tropic of Cancer will have the sun vertical on the 21st June at the summer solstice, and places on the tropic of Capricorn have a vertical sun on December 21st, the date of our winter solstice. To this motion of the sun we owe the different seasons—spring, summer, autumn, and winter. If the surface of the earth were uniform in character, all places on the same parallel of latitude would exhibit the same changes of temperature as the sun advanced or receded. Since, however, different portions of the surface so situated may consist either of land, water, or ice, the effect of the same quantity of heat in producing alterations of temperature will be very different under the different conditions of the surface.

During the summer months, when the sun is north of the equator and the days are longer than the nights, the northern hemisphere receives more heat from the sun than it gives out by radiation, and the temperature goes on increasing until it reaches the maximum in July, which is the hottest month in England. From July the thermometer falls steadily till January when the lowest readings occur. We thus see that the range of yearly temperature is governed by the same principle as that which regulates the daily temperature, since the highest readings occur after the time when the sun has reached his highest meridian altitude. In the frigid zones there is no day during one part of the year, and during the other no night. At the poles there is one day and one night in the year, each of six months' duration. In these regions the heat is exerted in a very different manner from that which prevails in lower latitudes, and both the diurnal and annual ranges of temperature will

be of an abnormal character. In India the change of temperature during the year is different in different parts of the country. The change is greater in magnitude in dry parts of the country than where it is damp and rainy. It is also greater in Northern India where the days are longer than in the south. The greatest range is at Leh, where the difference between the highest and lowest readings recorded during the year averages 94°. In the Punjab it varies from 80° to 86°. At Simla it is 63° and 47° at Darjiling. From the Punjab the annual range of temperature decreases eastwards to Bengal and Assam, and southwards to Ceylon, where it reaches its minimum. At Lucknow and Allahabad the average range is 76°, at Patna 68°, and Calcutta 54°. At Allahabad the extreme hot weather temperature is as high as that of the Punjab; but the lowest cold weather temperature is 36°, while the lowest in the Punjab is about 24°. During the cold season the temperature begins to rise from January or February until the beginning of the rains. When the first heavy fall of rain takes place the temperature sinks many degrees, and though it rises during temporary breaks in the rains, it does not reach the same intensity as it had during the months which preceded the rainy season.

The foregoing remarks on temperature refer exclusively to the temperature of the air at a place shaded from the sun, and taken under the conditions which are usual in such cases. The sun temperatures, as recorded in different countries and localities, supply us with the means of estimating and comparing the intensity of the sun's radiation at the various places where the observations are made. Several methods have been proposed for measuring the intensity of solar radiation; for our purpose, however, it will be sufficient to notice the one in most general use. The instrument employed is known as the black-bulb thermometer in vacuo, the construction of which is due to Sir John Herschel. It consists of a maximum thermometer, the bulb and stem of which have been coated with lamp

black. This is enclosed in a glass tube having a bulb of about $2\frac{1}{2}$ inches diameter at one end. The outer glass envelope is exhausted of air and hermetically sealed. The instrument so constructed is exposed to the sun by fixing it in a horizontal position at a height of about four feet above the ground. The site selected must be as far as possible from houses, trees, or other objects, which might intercept the sun's rays, and prevent them from falling on the instrument. The rays passing through the glass covering are absorbed by the blackened bulb, which again radiates back the heat to the outer envelope. The temperature of this latter is nearly the same as that of the air surrounding the thermometer. The rule for using the instrument is to take the highest readings registered by it for the day, and from this reading to deduct the maximum temperature of the same day recorded by an ordinary thermometer in the shade. In England readings of the black-bulb thermometer reaching to 150° are recorded. In India the difference between the temperature of the air and the sun temperature varies from 50° to 70°. It remains fairly constant throughout the year, so long as the sky is free from clouds. The measurements of solar radiation are greatly influenced by the amount of aqueous vapour present in the air. In a dry climate, such as that of Leh in Ladakh, the readings at an elevation of 11,500 feet sometimes reach 214°. This is explained by the fact that aqueous vapour when present in the air stops some of the rays which are travelling from the sun to the earth. It is a well-known phenomenon that at considerable elevations above the sea level, such as our hill-stations in India, the effect of the sun's rays is much greater than we should expect from the temperature of the air. The readings of the black-bulb thermometer show that at these stations the sun is really more powerful than on the plains. This is because the denser and damper portions of the atmosphere lie below, and in passing through the higher strata no appreciable amount of the sun's heat has been cut off.

A vertical beam in passing through the atmosphere loses 20 per cent. of its heat by absorption, while in the case of rays which are nearly horizontal, almost all the heat is absorbed. This explains why the sun is hotter at noon, when his rays fall vertically on the atmosphere, than after sunrise in the morning or before sunset in the evening, when the rays have to pass for a longer distance through the moist lower strata of the air. Of the total quantity of heat which arrives at the higher limit of the atmosphere, it is supposed that about three-fourths reach the sea level. The earth is not only receiving heat from the sun but is at the same time giving out heat by radiation into space. It is by means of this heat that the air is warmed, and not by the rays which come direct from the sun. The instrument used for measuring terrestrial radiation is a simple minimum thermometer. The thermometer is placed on green sward with its bulb on a level with the top of the grass. The lower the temperature recorded by the thermometer, the greater will be the escape of heat from the ground. The facility with which radiation takes place from the earth's surface depends to a considerable extent on the nature of the covering at the place. Grass and herbage radiate heat more freely than earth or gravel; hence we find that the night temperature on a plot of grass will fall below that of a gravel walk alongside of it. It is generally found that a minimum thermometer on the grass reads several degrees lower than one placed at the height of four feet above the ground. Nocturnal radiation affords an explanation of the method of preparing ice (*asmani baraf*), which has been so long practised in India. A piece of ground is selected lying east and west. In this beds are excavated to the depth of two feet, and filled with straw—loosely laid down to within about six inches of the surface of the ground. Water is poured into shallow dishes of porous earthenware, which have been placed close together on the surface of the straw. The straw being kept loose and perfectly dry prevents the access of heat from the surface of the ground underneath

it. Since the straw is a powerful radiator of heat, the temperature of the air in contact with the dishes is reduced some 20° below that which is found two or three feet above them. The water evaporates rapidly, and since this rapid production of vapour requires heat, the necessary heat is abstracted from the water, which is soon reduced to a temperature below the freezing-point and converted into ice. The ice is formed most rapidly when the wind is in the west or north-west—this being the driest wind. With an east or south wind no ice is formed, even if their temperature be lower than that of the north-west wind. This is because the air under such circumstances contains a greater quantity of moisture, on account of which the processes of evaporation and radiation are not sufficiently rapid to bring about the necessary reduction of temperature. No freezing takes place on nights when the wind blows rather strongly, since in this case the air cannot remain in contact with the beds long enough to cool down to the required temperature.

We have already stated that the key to the greater number of atmospheric changes is to be found in the fact that air flows from a region of high pressure to one of low pressure. This shows us that the pressure of the atmosphere is a factor of fundamental importance in all meteorological phenomena. This element is determined by the barometer. The principle of the barometer depends upon the fact that air exerts a downward pressure upon the surface of a liquid, or any body with which it is in contact. If then a tube from which the air has been withdrawn be inverted over mercury or any other fluid, that portion of the surface immediately below the tube will be relieved from pressure, and the liquid will be forced up the tube, until its weight becomes equal to the pressure exerted by the atmosphere. The liquid most commonly employed is mercury, since owing to its great weight a comparatively short column is needed to balance the pressure of the air. At the level of the sea this pressure amounts to about 14·7 lbs. on every square inch of surface.

The simplest form of barometer consists of a tube of wide bore standing vertically in a vessel containing mercury. The height of the column in the tube above the mercury in the vessel is measured on a graduated scale placed alongside of the tube. Since atmospheric changes of a very marked character often result from a small change in the height of the barometer, the observations connected with barometric readings are of a very delicate character, and various corrections have to be applied to the observed readings in order to arrive at the true pressure of the atmosphere. It is unnecessary to give further details on this part of the subject.

There is a widely prevalent belief that a high or low barometer may generally be regarded as a reliable indication of the kind of weather which may be looked for. A rise or fall in the barometer may, and often does, indicate a change of weather; but weather must be regarded as only one of several factors capable of producing fluctuations in the barometer. In dealing, therefore, with barometric readings, when the object is to ascertain how they are affected by changes in the weather, it becomes necessary to find out what causes other than weather changes are concerned in producing any given rise or fall. When these are known, and the effect due to them eliminated, the residual change may safely be set down to weather. We have to notice first that the height of the barometer at any place depends upon its height above the sea-level. The reading is lower the greater the elevation of the place, the fall amounting to about one inch for every 900 feet we ascend. The following figures, which give the average readings at different stations in India, show how they gradually diminish as the elevation increases. At Calcutta, where the observatory is 21 feet above the level of the sea, the average reading is 29·79 inches; at Allahabad, 307 feet above the sea, 29·48 inches; at Lahore, 732 feet above the sea, 29·08 inches; and at Simla, at a height of 7048 feet, 23·24 inches.

Barometric pressure has a yearly range, and this annual fluctuation must be allowed for in dealing with the observations at the place. In India the barometer is highest on the plains in December and January. From this time it falls till June and July; from August it begins to rise, and continues to do so until the end of the year.

In all latitudes there is a daily as well as an annual range of the barometer, for which allowance—in low latitudes at least—must always be made. Within the Arctic circle the daily oscillation merges in the annual. In the more northerly portions of the temperate zone, the daily fluctuation is hardly observable, except in very calm and settled weather. In England, the mean value of this variation amounts to ·02 of an inch, and is generally concealed by changes of greater amount. It is, however, a marked feature in the meteorology of the torrid zone, and any irregularity in its appearance may be regarded as a sign of a coming storm. In India the daily oscillation occurs with great regularity, and in the interpretation of barometric readings allowance must always be made for its effect. In that country the barometer rises from four in the morning to half-past nine; then falls till about four or five P.M. It rises again till about ten P.M., and falls till four A.M. These changes are independent of the weather, and amount to about one-tenth of an inch. The variations which indicate changes of weather are much smaller in India than they are in England. A fall of three-tenths of an inch may be regarded as the prelude to very unsettled weather, and it is only near the centre of a cyclone that the fall exceeds this amount.

Since the mercury in a barometer will behave in the same manner as the mercury of the thermometer, expanding and contracting with the rise and fall of the temperature, it is evident that when a change in the height of the barometer has taken place, a certain fraction of the change will be due to an alteration of temperature, unless, indeed, the latter has remained constant during the progress of the

change. A correction is, therefore, required on this account, which is effected by reducing the height of the column to that which it would have measured at the temperature of melting ice. The necessary corrections for different temperatures are given in handbooks of meteorology. The barometer readings, published in weather reports, have all been corrected for temperature, and this should be noticed when a comparison is made between any observed readings and those given in the reports. We have already seen that the reading of a barometer depends upon its height above the level of the sea. In order, therefore, to arrive at a correct value of the pressure of the atmosphere over an extended area, it is necessary to apply a correction for the different heights at which the readings have been taken. This is done by reducing the observed readings to the value they would have had at the sea-level. In this case the reading is said to be reduced to the level of the sea.

Very little can be inferred in regard to changes of weather from the readings of a single barometer. When all the corrections just referred to have been made, and the daily and yearly oscillations allowed for, it will be found that the barometer is constantly oscillating. According to Mr. Blanford, 'this rise and fall in India amounts to between one and two tenths of an inch, and is greater in Northern than Southern India. They do not necessarily betoken any important change of weather, though generally there is more cloud about the sky when the pressure is low than when it is higher, and it is at its low phase in the hot season that thunder-storms most frequently occur. In the cold season in Northern India, a fall is frequently accompanied with an easterly or southerly wind; the wind that precedes and brings the winter rains of Northern India. In the rainy season, a fall of greater amount precedes one of those bursts of heavy rain that throughout this season alternate with intervals of fine weather.' The same writer also states that when a cyclone

is generated far down the Bay of Bengal, which generally happens in May, October, and November, the barometer in the north of the Bay is but little affected, sometimes even rises during the formation of the storm, and only begins to fall when the storm moves northwards. The fall is at first slow, and becomes more rapid shortly before the storm reaches the neighbourhood of the place.

The nature of the weather which prevails at any place will be different according as the wind is dry or moist. Both the direction and force of the wind depend upon the relative distribution of pressure at any given time over a large extent of country, and not upon the actual reading of the barometer at any particular place. To ascertain this distribution, simultaneous observations of the height of the barometer should be made at as many different stations as possible within the given area, whether of land or sea. When these readings are compared, the direction of the wind may be inferred, since it is known that it will blow from where the pressure is high towards the region where it is low. When the different places are in telegraphic communication, the different readings are communicated to a central station where the distribution is mapped out. The place where, for the time being, the pressure is lowest is said to be the seat of a barometric depression, and as a general rule the heaviest fall of rain takes place in the neighbourhood of such a depression.

*Barometric Gradient.*—The force of the wind depends upon difference of pressure. The greater the difference of pressure between any two stations, the greater will be the flow of air from the one to the other. The barometric gradient is the term used for defining the rate at which the atmospheric pressure varies between two places. The units which have been chosen are ·01 inches for pressure, and 15 geographical miles for distance. This means that when the barometer falls $\frac{1}{100}$ of an inch in a distance of 15 geographical miles we have the unit gradient. Other gradients can be expressed in terms of this. It has been

found that the relation between the velocity of the wind and the barometric gradient cannot be expressed by a mathematical formula. The gradients are calculated for the sea-level, or, as it may be expressed, for a horizontal plane, and the wind does not in reality blow horizontally. With the same gradient the force of the wind on the open sea is greater than on land. Local irregularities in the surface of the ground also affect the velocity of the wind. Observations have been made on winds with velocity varying from 2 to 44 miles an hour at different heights above the surface of the ground extending up to 50 feet, and the results show that the distances passed over in the same time by the wind increase with the height above the ground.

*Barometric Charts.*—The distribution of atmospheric pressure over any region is shown on a chart constructed in the following manner. The readings of the barometer, after having been reduced to sea-level and corrected for temperature, are written against the station to which they refer. Lines are then drawn, passing through all the points where the pressure is the same. Such lines are termed isobaric lines or isobars. In constructing the chart the points chosen are those differing in pressure by one-tenth of an inch, and the spaces between consecutive lines will show where pressures are intermediate between those denoted by any two lines. The space enclosed within the isobar of lowest value is termed a barometric *depression*.

### Moisture of the Atmosphere.

We have already stated that the atmosphere, in addition to its two principal constituents, nitrogen and oxygen, contains a certain quantity of aqueous vapour. Though much smaller in amount than the other two gases, yet, from a meteorological point of view, aqueous vapour is of very great importance. When a vessel containing water is placed in the open air during dry weather, the water gradually diminishes in volume, having passed into the air in the form of vapour. This slow conversion of a

liquid into the gaseous form is named evaporation. Water is constantly evaporating from the surface of the sea, lakes, rivers, and the moist surface of the ground. The converse process, that, namely, by which vapour is changed into liquid, is termed condensation. Under certain circumstances the water which has passed into the air as vapour condenses, and falls as dew, rain, hail, and snow. The sun is the prime cause of this circulation of water in the air. It has been remarked that the atmosphere is a vast still, of which the sun is the furnace, and the sea the boiler, while the cool air of the upper atmosphere is the condenser, and we, on a wet day, catch some of the liquid which distils over.

On referring to the section which treats of gases, it will be seen that the volume of a gas increases or expands with an increase of temperature and diminishes as the temperature falls. On the other hand, the volume diminishes as the pressure increases, and *vice versâ*. Vapours, such as steam, obey the same law as gases within certain limits of temperature and pressure. If, however, the pressure be increased beyond a certain limit, or the temperature fall below a certain value, a portion of the vapour condenses. This also happens when the vapour is mixed with other gases, as is the case in the atmosphere. A given mass of air under a fixed condition of temperature and pressure can contain only a certain amount of water in the form of vapour. If the pressure be increased, or the temperature lowered, a part of the vapour condenses, and only as much remains as is suited to the new conditions of pressure and temperature. When the quantity of vapour in the air is such that any increase in the pressure and lowering of the temperature would produce condensation, the air is said to be saturated. When, on the other hand, the air is not fully saturated, and water is present, an additional quantity will evaporate until the point of saturation is reached. When water or any other liquid evaporates it absorbs a certain quantity of heat in

passing from the liquid to the gaseous state. The heat required to produce this change of state is abstracted from neighbouring bodies, and, as a result of this loss of heat, their temperature is reduced. This principle explains the cooling effect of a *Khus tattie* during a hot wind in India. The tattie being kept constantly moist, the hot wind on passing through it produces rapid evaporation of the water with which it has been saturated. The heat required to form the vapour is taken from the wind, which is thus reduced many degrees in temperature during its passage through the moist grass. It is well known also that a wet cloth wrapped round a *surai,* or a bottle of water will preserve the contents refreshingly cool during a hot and dry wind. The cooling effect is in this case also due to evaporation from the wet cloth. The necessary heat is taken from the liquid inside the vessel, which is by this means reduced in temperature. Measurements in regard to the amount of evaporation are of a very uncertain character. Certain conditions which affect the greater or less rapidity with which it takes place are known. (1) Evaporation takes place more quickly when the temperature is high than when it is low. (2) The rate of evaporation will be greater in a high wind than when the air is still, since the water will give off vapour the more rapidly the faster the air in contact with the water is changed. We see from this that when water is poured into a vessel or evaporating pan for the purpose of measuring evaporation the vessel should be kept full; since, if it fall below the rim, there will be a layer of air resting on the surface of the water, which cannot be renewed so readily as the air above the rim. Careful observations have been made in regard to the amount of evaporation from water surfaces in different parts of India, and the results of these observation are summed up by Mr. Blanford as follows:—'Allowing for differences of climate, the results of these several observations are sufficiently consistent, and it may be concluded with some confidence that the loss by

evaporation of large fresh-water tanks in India varies from rather more than one-ninth of an inch daily, on the average of the dry season, in the comparatively damp climate of Bombay, to about one-third of an inch as a possible maximum in the very dry, hot climate of the Deccan; probably less.'

A comparison between the rainfall and evaporation in different countries leads to the conclusion that in nearly all parts of the globe, not too remote from the sea-coast, the rainfall is nearly equal to the evaporation, and that there cannot be a great transference of vapour from the torrid to the temperate zones.

*Hygrometry.*—We have already seen that the air may contain more or less vapour, and that when it contains as much as it is capable of holding at a particular temperature it is said to be saturated. Hygrometry (from the Greek *hygros* wet, and *metron* a measure) is the science of measuring the degree of saturation of the air, or, as it is generally named, the humidity. When we speak of the *humidity* of the air, we mean the ratio of the amount of vapour actually present in the air at a certain temperature to the amount which it would contain if it were fully saturated. Saturated air is here taken as the standard, and the degree of humidity is generally expressed as a percentage of the saturating quantity of vapour. For example, if the *humidity* is stated to be 50, the meaning is that the air contains half the quantity of vapour which it is capable of taking up at that temperature.

The instruments employed for determining the humidity of the air are named hygrometers. Of these there are a great many varieties, the one most commonly used being that known as the wet-and-dry-bulb hygrometer. It consists of two thermometers, one of which shows the temperature of the air; the other has its bulb covered with a single fold of muslin which is kept moist with water. The principle of the instrument is, that so long as the air is not saturated evaporation will take place from the moist covering of the

wet bulb, and the temperature of this thermometer will fall since heat has been withdrawn from it to form the vapour. It becomes stationary as soon as it has reached a certain temperature intermediate between that of the dry bulb, and the temperature of the dew-point. From the readings of these two thermometers the humidity is found by the use of special tables. If the air be saturated, no evaporation can take place, and the two thermometers will read alike. 7, 990

In considering how far the observations made by hygrometers represent the true state of the atmosphere with regard to moisture, it is to be remembered that by this means we can only ascertain the amount of vapour in the portion of air in contact with the instrument, and from what has been said with regard to evaporation, it is evident that the wind will also affect the readings of the wet-bulb hygrometer. The amount of vapour in any locality will to some extent depend upon its surroundings. Near evaporating surfaces of water the air will contain more moisture than the air over places more remote from such sources of supply. The amount of vapour, like the temperature, diminishes as we ascend vertically above the surface of the earth, but the former decreases with the height more rapidly than the latter. It has been calculated that one half of the vapour present in the atmosphere is contained in the lowest 6000 feet, and that the quantity at a height exceeding 20,000 feet is only one-tenth of that at the surface of the ground. From the observations of Captain Basil Hall, in ascending the Peak of Teneriffe, it would appear that the decrease in the quantity of vapour does not take place at a uniform rate. After getting wet at one part of the ascent, he found the air at the top of the mountain very dry, and on descending he again passed through the damp stratum. These considerations show that we cannot rely on isolated hygrometric observations made at the surface of the earth for precise information as to the general distribution of vapour in the atmosphere.

In India the humidity of the air is subject to great variation. According to Mr. Blanford, the air is sometimes saturated or has a humidity of 100 during a spell of very wet weather in the rains. But when the hot wind is blowing, as it does in the Upper Provinces during April and May, it is sometimes less than 10 and has been known to fall to 3. At Agra the mean for the month of May 1884 was 20. The average humidity for May in Scotland, which is there the driest month, is 73. The same writer also explains that the dryness of the hot winds in India is not entirely due to the direct warming of the air, but is due to the aërial circulation produced by the unequal heating of the atmosphere. The damp and more highly heated layer of air in contact with the ground being lighter ascends, and is replaced by drier and originally cooler air from a higher level. The hot winds are part of an air current coming originally from the western mountains, and blowing at a great height above the earth's surface. They are brought down to the lower level by the circulatory movement just mentioned. Originally a cool wind, it is soon warmed both by its descent (heat due to compression) and by contact with the heated earth. 'The well-known healthiness of the hot season may be due in some measure to this stirring up of the atmosphere, the removal of mephitic exhalations, and the invasion of the lower atmosphere by the purer air drawn from the mountain zone.'

*Precipitation.*—The water which has passed into the atmosphere in the form of vapour is given back to the earth as dew, rain, or snow.

*Dew.*—This is the condensation of moisture without the formation of visible clouds. The true explanation of its formation was first given by Dr. Wells, a London physician who lived in the early part of the present century. We have already seen under radiation that while the earth is receiving and absorbing heat from the sun, it is also giving out heat by radiation into space. In the evening after

sunset the earth is still parting with its heat, but since it is now receiving none in return its temperature falls. With this reduction of temperature the air in contact with the surface of the ground is also cooled, and by degrees the temperature is reached at which the vapour present in the air is sufficient to produce saturation. This point is called the dew-point. Any additional fall of temperature will be attended with the condensation of a portion of the vapour contained in the air, and this condensed vapour, deposited for the most part on grass and other herbage, receives the name of dew. When the sky is clouded the greater part of the heat radiated by the earth is reflected back from the clouds, and the temperature of the air does not sink to the dew-point. It will accordingly be found that on cloudy nights there is no deposition of dew. If again the dew point be below the freezing-point, the moisture which is deposited assumes at once the solid form, and in this case we have the phenomenon of hoar-frost. Both dew and hoar-frost will be deposited most copiously on those objects which are the best radiators of heat. It is for this reason that we find grass, trees, and vegetables covered with dew, while dry roads or the bare surface of the ground show no trace of a deposit.

When vapour is condensed during the formation of dew and hoar-frost, the latent heat of the vapour is set free, and this heat retards to some extent the cooling of the atmosphere. On this account the temperature of the surface of the ground cannot easily fall below the temperature of the dew-point which existed at night-fall. For if it should sink lower, a further condensation of moisture will take place, which, by setting free more heat, will again raise the temperature. Mr. Scott, in his meteorology, calls attention to this point as being of importance to gardeners and others interested in the rearing of plants; for by observing the dew-point in the evening they will be able to form a probable estimate of the lowest temperature likely to occur during the night. If the dew-point

on the grass be above the freezing-point they need not fear the occurrence of hoar-frost; but if it should be below this, it will be advisable for them to cover up delicate plants to prevent their being nipped if the sky should clear before morning.

Dew cannot appear when the wind is strong, since the air cannot remain in contact with the ground long enough to admit of its temperature being reduced to the dew-point.

### Fog—Mist—Cloud.

Passing from the consideration of the humidity of the air, we have now to notice as briefly as possible what takes place when the limit of saturation is past and water is deposited. True aqueous vapour is invisible, and it is only when it is condensed and becomes disseminated through the air in a state of very minute division that it becomes opaque. When the vapour condenses, it first assumes the form of very small drops such as we see in fog or cloud. These afterwards coalesce to form rain or snow, the forms in which the greater part of the vapour of the air falls to the earth. Fogs frequently result from the mixing of two masses of air at different temperatures. When the temperature of the mixture is lower than that which is required to maintain in the state of vapour the moisture contained in the two masses, part of it is condensed, and produces what is known as fog. Fog may also be caused by the flow of a current of warm moist air over masses of ice such as are sometimes encountered by vessels in the Atlantic. Fogs of this character are often met with on the banks of Newfoundland.

Mist differs from fog only in having the particles of moisture somewhat larger, and on this account a person exposed to it will get wet more quickly than he would through exposure to a fog.

Clouds are really of the same nature as fog. Even in dry weather one may sometimes see the summit of a mountain capped by a mass of heavy cloud, but those

who are enveloped in it find it to be nothing more than fog. The general cause of the formation of clouds is the ascent of air more or less moist, and its consequent chilling below the dew-point in the higher regions of the atmosphere. Drops of water, no matter how small, are heavier than air, and consequently a cloud which is made up of an infinitely large number of minute drops must be falling towards the earth under the action of gravity. At the same time the cloud appears to be floating or suspended in the air. In order to explain this so-called 'floating' of clouds, we shall suppose one or two experiments to be made on three fluids, honey, water, and air—which differ from each other in consistency or viscosity. If we drop a cannon-ball into a tank filled with honey, it will sink pretty rapidly in this substance, bullets will sink more slowly, and small shot very slowly. If we now take water instead of honey we shall find that in it even the small shot will sink quickly, but a finely ground metallic powder slowly. This same powder might yet be coarse enough to fall quickly in air, while a still finer dust would fall slowly. We may thus easily conceive that when the particles of matter are sufficiently minute—such as those droplets of water of which clouds are composed—the air would behave to them in the same way that honey would to fine shot or water to finely divided metallic powder. We thus see that the minute drops of water which make up clouds—being heavier than air—are falling, but owing to the viscosity of the air are falling slowly. When the air is free from wind, every cloud is falling, but as it descends it comes into warmer air, and its under surface becomes converted into invisible vapour, and on this account it appears to remain at a constant height. Very frequently this slow descent of clouds is disguised by larger movements due to other causes. All clouds are not, however, composed of water. The clouds of the upper stratum are believed to consist of small needles of ice. This is inferred from the fact that at the height at

which these clouds float the temperature must be so low that water could not exist in the liquid state. Certain phenomena known as halos and mock suns are produced by the higher clouds only, and these appearances can only be explained on the supposition that the light has been refracted through prisms of ice.

The classification of clouds which has hitherto been generally adopted in text-books of meteorology is that of Mr. Luke Howard. Mr. Blanford, in his *Practical Guide to the Climates and weather of India, Ceylon, and Burmah,* has given a new classification proposed by Professor Hildebrandsson of Upsala and the Hon. Ralph Abercromby, and this he considers will most probably become the basis of the future classification of clouds. These observers have had ample opportunities of studying the various forms of clouds in different parts of the world, and have had recourse to photography to record their observations. They have also established the connection between the cloud-forms and the weather conditions in which they occur. Their observations lead to the conclusion that the forms are much the same in all parts of the world, the chief difference being that certain forms are more common in one place, others in another. With regard to this scheme —which is that reproduced here—Mr. Blanford remarks that it recognises the very important distinction between such clouds as are characteristic of fine, and such as betoken or accompany rainy weather.

Messrs. Hildebrandsson and Abercromby's proposed Scheme of Cloud Classification.

*a. Discrete tending to rounded forms (principally in dry weather).*

*β. Extended and sheet-like forms (rainy weather).*

*A.*—Highest Clouds, mean height 30,000 feet.

1. Fibre cloud [*Cirrus* or mares' tails].

2. Thin cloud veil [*Cirro-stratus*].

*B.*—Medium elevation 13,000 to 20,000 feet.

3. Small globular cloudlets shining white like silk, 20,000 feet [*Cirro-cumulus*, mackerel sky].

4. Larger globular, like white wool, 13,000 feet [*Cumulo-cirrus*].

5. Thicker, ash-coloured, or bluish-grey sheet, 17,000 feet [*Strato-cirrus*].

*C.*—Lower Clouds, 5000 to 7000 feet.

6. Great rounded masses or rolls of grey cloud [*Strato-cumulus*].

7. Ragged sheets of grey cloud from which rain commonly falls [*Nimbus*].

*D.*—Clouds in ascending air-currents.

8. Heap Cloud [*Cumulus*]. Summits at 6000 feet; bases at 4500 feet.

9. Storm (thunder) clouds [*Cumulo nimbus*]. Summits 10,000 to 16,000 feet; bases 4500 feet.

*E.*—Elevated fogs. Below 3500 feet [*Stratus*].

The heights given in the above table are the measurements for Northern Europe. Owing to the higher temperature which prevails in India, the measurements for that country would have to be increased. When clouds show a tendency to form sheets, which are at first thin and high up in the sky, but gradually become darker and sink lower, they generally portend rain. But if the sheet appears to break up into separate masses, and the sun begins to shine through these, fine weather may be looked for. With regard to the motion of clouds, it will be found that the lower clouds usually move in the same direction as the wind at the earth's surface; but their motion is at all times more rapid. The direction of the motion of the higher clouds almost invariably makes an angle with that of the wind below, and on this account the movements of these clouds supply much information in regard to atmospheric currents.

The amount of cloud which is visible in the sky at any time is estimated on a scale 0-10, 0 denoting a clear sky, and 10 a sky entirely overcast. The average cloudiness of a day or a month at any place is found by taking the mean of all the observations which have been taken during the period. The cloud proportion over the greater part of India is below 5, this amount being exceeded at only a few stations in the south, and in Ceylon and Assam. The two cloudiest months over nearly the whole of India are July and August. In the parts of the Punjab and Upper Sind, which the summer rains do not reach, there is most cloud in February and March.

*Rain.*—By far the greater part of the vapour which is contained in the air is restored to the earth in the form of rain. The quantity of rain which falls at any particular place is measured by means of a rain-gauge. This instrument consists essentially of a funnel into which the rain falls, and a vessel to receive and collect it. The water which has been collected is measured in a graduated glass, which gives true inches for the aperture of the gauge.

Rain is caused by the cooling of air charged with moisture. This may take place in several ways.

(1.) When a current of damp air ascends into the higher regions of the atmosphere it is reduced in temperature. The cooling is due to the fact that the air in ascending has to do work both in expanding and in pushing aside the superincumbent atmosphere. This process is nearly always in action in the equatorial regions of the globe. Dr. Hann has calculated that the temperature of ascending air, if dry, is lowered 1° Fahr. for 182 feet of ascent. Air, if perfectly dry, which had ascended to a height of 28,000 feet, the highest point of the Himalayas, would suffer a reduction in temperature of about 153° Fahr. The air, however, always contains a certain quantity of moisture, which on condensing liberates its latent heat, and in this way retards the cooling of the

ascending air. As soon as the temperature reaches the point of saturation, the condensed vapour falls as rain.

(2.) A second cause of rain is due to the contact of warm and damp air with the colder surface of the ground. To this cause is due the greater part of the rain which falls on the west coast of England in winter. The surface of the ground is then colder than the sea, and the lower stratum of moist air coming in contact with the ground becomes cooled and deposits its moisture. The west coasts are also mountainous, and on this account the air being forced to ascend a further reduction in temperature will be brought about so as to cause an increase in the fall of rain.

(3.) When two masses of saturated air at different temperatures meet and mix, the temperature of the mixture will be too low to retain the whole of the moisture in the form of vapour. The excess will condense, and if of small amount will take the form of cloud or mist, and if the quantity be larger it will fall as rain.

The average annual rainfall for the British Isles varies from 60 to 80 inches on the west coasts of Ireland and Scotland to about 20 inches on the east coast of England. The following particulars regarding the rainfall of India have been abridged from Mr. Blanford's *Practical Guide to the Climate of India* already referred to.

The first point to be noticed in connection with the rainfall of India is the wide diversity which exists in the amount which falls in different parts of the country. This contrast is most marked in Northern India, where Cherrapunji in the Khasi hills has an annual fall of from 500 to 600 inches, while Jacobabad in the west shows an average of about 4½ inches. Between these extremes there exists every possible variation. Another noteworthy peculiarity is the variability of different parts of the country in respect to the regularity of the rainfall. The provinces which have the lowest rainfall are those in which it is most

irregular, while the rainy parts show also the greatest regularity with respect to the yearly averages. It is to be noticed, however, that this does not hold good in every case, for the rainfall of the Central Provinces, which only reaches the moderate amount of 50 inches, is yet very regular, and the country hardly ever suffers from drought. The North-west Provinces, where the average rainfall is 36 inches, are more liable to the vicissitudes here referred to, and have passed through several periods of severe drought during the present century.

With regard to the geographical distribution of the rainfall, it is to be noted that along the west coast of both peninsulas, where the summer monsoon blows full on the land, there is a belt of very heavy rainfall. In both cases, at a distance of about 50 miles from the sea, a range of mountains runs parallel with the coast. Over the whole of the tract which lies between the sea and the range of hills, the rainfall varies from 100 to 250 inches. In the western peninsula the belt of high rainfall narrows very rapidly north of Bombay. In the eastern peninsula it extends northwards beyond the shores of the Bay of Bengal, through Eastern Bengal and Cachar, and along the face of the Khasi hills until it joins on to the similar zone which runs east and west along the face of the Himalayas. This latter zone has not been traced in a westerly direction beyond Sikkim. Eastward it extends to the upper end of the valley of Assam. The zone of heavy rainfall on the face of the Himalayas does not extend far into the mountains.

From the Gulf of Cambay a band of moderately high rainfall extends eastwards across India. It occupies all North-eastern India, extends to the valley of the Ganges on the north, and on the south covers the drainage basin of the Godavery down to the delta of that river and the Kistna. From Allahabad an offshoot runs up to the north-west, including the Gangetic plain north of the Ganges, and continues through the northern Punjab and along the

face of the Himalayas as far as the Indus valley. The average rainfall of the whole of India up to the foot of the Himalayas, excluding Burmah, has been calculated to be 42 inches in the year.

The principal season of rainfall over the greater part of India is during the summer monsoon, from June to October. This applies to the greater part of Western India, Bengal, the North-west Provinces, Central India, the Central Provinces, Rajputana, Hyderabad, the Deccan, Berar, Guzerat, and the whole of the west coast of the peninsula. But while the main body of the monsoon is directed towards Northern and Central India, very little rain falls on the eastern peninsula, the Carnatic, and the Eastern Ghats. There the season of heaviest rainfall occurs from October to December, when the north-east winds begin to blow in the north-west of the bay.

In the Punjab and Rajputana, the summer rains are very irregular. They seldom extend as far as the Indus or beyond the first snowy range in the Himalayas. In the interior of these mountains and the high plains beyond the north-western frontier, in Afghanistan and Baluchistan, snow falls principally during the winter months and in the early spring. On the lower ranges of the hills, and on the plains of the Punjab, rain falls at intervals during the season. During the winter months also these rains sometimes extend to the Gangetic plain, and more rarely to Bengal. In the spring, when the sea winds begin to blow strongly on the south and east of the peninsula and in lower Bengal, thunder-storms accompanied with heavy showers often occur. In Southern India the spring rains, known as 'Mango showers,' sometimes amount to several inches. These spring showers sometimes take the form of hail, both on the plains and on the hills.

It appears then that during every season of the year rain falls in one part or other of India. From June to October the south-west monsoon brings 'the rains,' extending over the greater part of the country. On the cessation

of these the rains of the Carnatic occur during the last three months of the year. These are followed by the winter rains of Northern India. Next come the spring showers of Southern India and Bengal, which last until the breaking of a new monsoon.

When the average rainfall of any place for a certain time is divided by the number of rainy days at the same place for the same time, the result will be the average amount of rain falling on each rainy day. This average is between six and seven-tenths of an inch on the plains of Bengal and the North-west Provinces, and in parts of Central India and the Central Provinces. On the west coast and on the Western Ghats it is higher. At Cherrapunji the average is 2·6 inches; at Akyab, Moulmein, Mahableshwur, and Matheran from 1 to 2 inches.

In the Deccan and Mysore, and in the Indus valley, it is only between three and four-tenths, and at Leh one-tenth of an inch. These results show that the average daily fall of rain on the plains of India is from three to seven times greater than in Western Europe. The following quotation from Mr. Blanford, given in his own words, well describes the results which follow from the peculiar character of tropical rainfall: 'In consequence of this character of Indian, in common with tropical rainfall generally, it is less penetrating in proportion to its quantity than in countries where much of it falls in a state of fine division, allowing time for its absorption by the ground. Instead of feeding perennial springs, and nourishing an absorbent cushion of green herbage, the greater part flows off the surface, and fills the dry beds of drains and water-courses with temporary torrents. In uncultivated tracts, where jungle fires have destroyed the withered grass and bushy undergrowth, and have laid bare the soil and hardened its surface, this action is greatly enhanced, and while all perennial water supplies which depend on the absorbed rain are either greatly reduced or altogether suppressed, a rainfall, which if husbanded by nature and art would

suffice for the agriculture and domestic requirements of the population, is thrown into the nullahs and rivers, and not only is wasted and lost for any useful purpose, but by producing floods becomes an agent of destruction.'

The extent to which the annual average of rainfall is liable to deviate from the normal amount is greatest in the driest parts of the country. In Sind the mean annual deviation is 37 per cent. of the average; while in Assam, where the climate is moist, the deviation is only 5 per cent. Next to Sind, the North-west Provinces and Oudh are the most liable to suffer from these vicissitudes in the rainfall, the mean annual deviation being 23 per cent., and within the last twenty-two years it has been 47 per cent. above and 39 per cent. below the average. Burmah, Lower Bengal, Chuta Nagpur, and the Central Provinces rank next to Assam in point of regularity.

The rainfall is never either deficient or excessive over the whole of India in one year. When the rains are heavy in Bengal, they are usually light in Bombay and Hyderabad, and *vice versâ.* On the average about two-thirds of India varies in one way, and one-third in the opposite. It has been supposed by some that rainfall and certain other meteorological phenomena are subject to periodic fluctuations, coincident with the variation which is known to occur in the number and size of the sun-spots. Periods of maximum and minimum sun-spot frequency recur every eleven years; and several English and some foreign observers are of opinion that a similar periodicity exists in regard to cyclones, rainfall, magnetic storms, Aurora Borealis, terrestrial temperature, and barometric pressure. If it should be established after more extended observation that a connection really exists between the two sets of phenomena, it will be possible to some extent to predict the advent of famines, floods, good or bad harvests, to foretell the probable price of grain, and the occurrence of commercial panics, incidents which are all more or less closely connected with the weather. At present

different investigators arrive at different conclusions as to the nature of the connection, some maintaining that a large number of sun-spots is associated with a high temperature, while others assert that it is associated with a low temperature. Mr. Blanford states that taking the last twenty-two years the rainfall of India *as a whole* does not indicate any such variation as is here referred to.

At the same time the rains of the Carnatic, which occur later than the heavy rains of other parts of India, showed a somewhat striking fluctuation in the eleven years 1864 to 1874, as also to some extent in the next eleven years 1875 to 1885.

The late Mr. Hill of Allahabad has adduced some evidence pointing to a similar variation in the *winter* rainfall of Northern India. An unusually heavy winter rainfall in the Upper Provinces means a large accumulation of snow in the Himalayas, which, in Mr. Blanford's opinion, has the effect of retarding the advent of the summer rains. On this point he writes: 'As far as our limited experience goes, seasons in which the accumulation of snow has been excessive have always been followed by a more or less prolonged suspension of the summer rainfall, as a rule in Northern India, but sometimes in some portion of the peninsula. It must, however, be added that there have also been serious droughts which, as far as our information goes, have not been preceded by any unusual snowfall on the mountains in the earlier months of the year, so that even if this be a cause of drought, which many considerations render probable, it is not the sole determining cause. The immediate cause of drought is the unseasonable persistence of dry land-winds to the exclusion of the rain-bearing wind of the summer monsoon.'

### Circulation of the Atmosphere.

The circulation of the atmosphere depends upon the relative distribution of pressure throughout its entire mass, in the vertical as well as in the lateral direction. Since

this distribution of pressure is greatly affected by temperature, it will be necessary to consider the effect which the temperature of the air produces on the pressure. If we were to suppose the earth at rest, and the temperature uniform over its entire surface, the atmosphere would form an envelope consisting of different layers concentric with the earth. The density, and consequently the pressure throughout each layer or shell, would be the same, and would vary according to a law depending upon the distance of each from the centre of the earth. The surfaces of equal pressure would all form the surfaces of spheres concentric with the earth, and consequently each of these surfaces would everywhere be at the same height above the level of the sea. In such a state of things we should have a stagnant atmosphere, since there would be no force at work tending to disturb the equilibrium. If now a portion of the earth's surface receive an additional supply of heat, the air in contact with the heated surface will be raised in temperature and will expand; the portion of the surfaces of equal pressure immediately over the heated ground will be pushed up to a greater height, the lower ones being more raised than the upper. The result of this will be that the point of the atmosphere where any particular pressure existed will now be raised to a greater height. In order to illustrate how this happens we may suppose a column of air to be confined in a cylinder extending beyond the limit of the atmosphere, so that the air if heated can only expand in the vertical direction. After having been heated the total weight of air will remain the same as before, since none of it can escape laterally; but at any given height in the cylinder the pressure will be greater than when the air was at the original temperature. This is evidently the case, since after expansion the weight of air above the level of any given section is greater than at first.

That an action similar to this goes on in the atmosphere may be shown by a comparison of the following barometric

readings, taken at different elevations in winter and summer :—

| Place | Elevation | Pressure January Inches | Pressure July Inches | Difference Inches |
|---|---|---|---|---|
| Geneva, | 1335 | 28·66 | 28·66 | 0·00 |
| Great St. Bernard, | 8174 | 22·11 | 22·39 | 0·28 |
| Col St. Theodule, | 10,899 | 19·77 | 20·16 | 0·39 |

These readings show that at the lowest of the three stations the pressure remains the same for January and July, but as the elevation increases the pressure for July, the warmest month, is ·28 inches higher than that for January, and at the height of 10,899 the difference amounts to ·39 inches. Since the air is most heated in the regions near the equator, the atmosphere, in accordance with the above principle, will there shoot up to the greatest elevation, and the pressure in the upper levels in the equatorial regions will be greater than those at the same height in higher latitudes. Under these circumstances a movement of the air will take place from the locality where the pressure is highest towards the regions where it is lowest, and air will flow over from the equator towards both poles, thus tending to produce equality of pressure at the same height above the earth's surface at all parts of the globe.

The result of this overflow of air will be to lower the pressure near the equator, and to increase it in the higher latitudes, since the air which has come from the equator will add to the weight of the atmosphere of the place at which it arrives. As illustrating this point, the two following barometric readings are instructive. The pressures are the mean of those taken at two different levels at the equator and near the 40th parallel of latitude :—

| | Equator Inches | Lat. 39° N. Inches |
|---|---|---|
| Pressure at sea-level, | 29·88 | 30·20 |
| ,, 13,000 feet, | 18·55 | 18·04 |

We thus see that at the sea-level the pressure increases with the latitude, while at the higher level it is greatest at the equator.

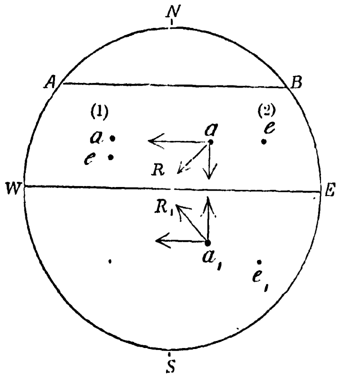
This distribution of pressure in the upper and lower regions of the atmosphere will give rise to two currents in each of the two hemispheres, an upper current from the equator towards both poles, and an under current from the north and south pole respectively towards the equator. A current of air flowing from the equator, and converging on the pole, will, as it proceeds, be gradually forced to make its way through a narrowing channel, and on this account the stream of air sinks to the surface of the earth before it can reach the pole. Observation shows that the upper currents descend to the level of the sea about the 30th parallel of latitude. Meeting the currents from the pole they produce the calms known as those of Cancer and Capricorn, and give rise to the high pressures which prevail in the neighbourhood of the 30th parallel of latitude in both hemispheres. It has to be noticed that this general movement of the atmosphere proceeds in spite of other circulations on a smaller scale, and of a temporary or local character, which may be going on at the same time at particular localities in certain parts of the globe.

The local winds known as land and sea breezes, or even the great monsoon system of the Eastern hemisphere, are only to be regarded as local interruptions of this general circulation. The overflow of air from the equatorial regions takes place at a great height, as is shown by the fact that the current has never been encountered on any of the peaks of the equatorial Andes. Its existence is, however, inferred from the motion of the higher clouds, which are seen to be moving in a direction opposite to that of the trade-wind below. Ashes from volcanoes in Central America have been carried to places which they could only have reached if carried by a current flowing in the opposite direction to the trade-wind. In January 1835 ashes from

Coseguina on the Bay of Fonseca were in four days conveyed to Kingston in Jamaica in the teeth of the trade-wind. Other instances of a similar nature are on record. The upper currents, on reaching the earth about the latitude of the tropics, become involved in the lower current, and are carried back towards the equator. At higher latitudes than those just named the persistence of upper and under currents can no longer be traced, but the prevalent direction of the wind is from the equator towards the poles.

The under currents blowing from the poles towards the equator are known as the Trade Winds. These winds have been long known to mariners, who, before the days of steam-ships, used to fix the seasons for their voyages so as to have both the Trade Wind and the South-west Monsoon in their favour. The Spaniards called the Trade wind region the 'Ladies' Bay,' since after reaching it a girl might take the helm. These winds are known as the North-east and South-east Trades respectively, the former blowing in the northern hemisphere, and the latter in the southern. Since these winds are produced by currents coming from the poles directed towards the equator, we might expect that on one hemisphere the wind would blow from the north, and in the other from the south. The true explanation of their actual directions from N.E. and S.E. was first given by Hadley in 1735. It hinges upon the fact that we have to consider not only the motion of the wind from the poles towards the equator, but also the modification of this motion introduced by the rotation of the earth on its axis. The earth turns from west to east on an axis, the extremities of which are the north and south poles. The time of performing one revolution is 24 hours, and since the equatorial circumference is 24,900 miles, it follows that a point on the equator will have a velocity of nearly 1038 miles an hour, a point situated exactly at either pole will be at rest, and points intermediate between these two extremes will have

smaller velocities the nearer they are to one of the poles. In latitude 30° the velocity of a point will be 900 miles an hour, and in latitude 60° exactly half the velocity at the equator, or 519 miles an hour. It must be borne in mind that the earth in its rotation from west to east carries the atmosphere with it. We have already seen that owing to the overflow of air from the equatorial regions towards the poles the pressure of the atmosphere at the equator is less than it is in higher latitudes, and that in consequence of this inequality a current will set in from the higher latitudes towards the equator. We shall first consider what takes place in the northern hemisphere. The accompanying figure may be supposed to represent




the earth, the diameter *WE*. being the equator, *N* the north pole, the opposite point *S* the south pole, *E* on the right hand the east, and *W* on the left hand the west. Suppose *AB* to represent the parallel of latitude 60° N, and that air starting from there moves towards the equator. This air will have the same west-to-east velocity as the earth has at *AB*., namely half that at the equator, and it will still retain this velocity on coming up to the equator. If we now consider a particle of air *a* and a point *e* on the surface of the earth which are together at (1), and compare their relative positions an instant later we should find them to be situated as in (2), since the velocity of *e* towards the east is greater than that of *a*; in other words, *a* will lag behind *e*. and, relative to *e*, *a* will appear to have a motion from east to west. It has at the same time a certain velocity from north to south, and when the two

velocities are combined by the principles of mechanics the resultant direction of the wind R. in the northern hemisphere is from the north-east. Similarly, air moving from the direction of the south pole towards the equator will on nearing the equator lag behind the earth, so that the particle of air $a_{\prime}$ in the southern hemisphere will also have a velocity from east to west relatively to $e_{\prime}$. It has at the same time a velocity from the south towards the equator, and the combined effect of these two velocities will be to produce a wind blowing from the south-east in the direction R. In the northern hemisphere we shall thus have a north-east trade, and in the southern hemisphere a south-east trade. The upper currents flowing from the equator towards the poles—or as they have been named the 'anti-trades'—will have a motion towards the east relative to places considerably distant from the equator, and in consequence of this velocity, combined with the other component, we shall have in the northern hemisphere a south-west wind, and in the southern hemisphere a wind from the north-west. The large continents in the northern hemisphere, being subject to great changes of temperature from summer to winter, modify these winds to such an extent in the northern hemisphere, that it is only over the oceans that they blow with any regularity. In the southern hemisphere, where there is comparatively little land to give rise to a disturbing influence, they attain great force, and in the latitude where they prevail are known as the 'roaring forties.' This circulation of the atmosphere undergoes considerable modification in the course of the year. In March, when the surface temperature of the Atlantic is lowest, the north-east trade does not extend so far north by 9° as in September when the temperature of that ocean is lowest.

There are in each hemisphere four belts of winds.

(1.) The equatorial calm belt with variable winds close to the equator.

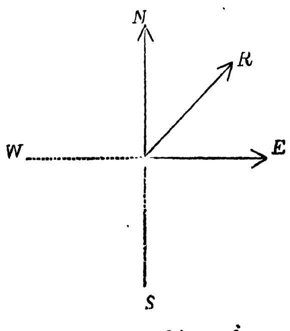
(2.) The belt which is constantly in the trade-wind throughout the year.

(3.) The belt which is in the trade-wind in summer, and outside of it in winter.

(4.) The belt of variable winds, chiefly westerly, which lies on the polar side of the trade-wind region.

If the earth were completely covered with water, the arrangement of winds above indicated would prevail over the entire surface of the globe. But since the land and the sea are very unequally heated by the sun, considerable modifications due to this fact are introduced. When the temperature of the land is higher than that of the sea, a current of air flows from the sea towards the land, and when the land temperature is lower than that of the sea, a breeze sets in from the land towards the sea.

The most prominent example of a reversal of the winds due to this cause is that which takes place every six months in India, and over the whole of southern Asia. When the sun is north of the equator the land surface of Northern India becomes more heated than that of the surrounding seas. The air over this heated region expands, producing a decrease of pressure, and in consequence of this the south-east trade is drawn across the equator towards the region of low pressure. When this wind has travelled for some distance to the north of the equator, it comes to places where the velocity of rotation of a point on the earth's surface is less than when it crossed the equator. From this it will be seen to follow that north of the equator the wind will have a motion towards the east relative to points on the earth's surface. This velocity, combined with that towards the north, gives rise to a south-west wind R.



This wind is known as the south-west monsoon, and blows in India during the summer months. The time when the direction of the wind changes is called the 'Breaking of the Monsoon.' This south-west wind coming from the Indian Ocean is highly charged with moisture, which is condensed and falls as rain over the plains of India. With its advent the rainy season in India begins, and lasts from June till October. After this the land wind is re-established, and with it there is a return to dry weather. The direction of the wind is not strictly south-west, except in the Bay of Bengal and the western part of the Arabian Sea. In other cases it undergoes local modifications. In the Ganges valley it blows from the south-east towards the heated plains of the Punjab. Along the coast of China it partakes more of a southerly direction. Europeans first became acquainted with these periodical winds when the troops of Alexander the Great reached the shores of the Indian Ocean. Aristotle has described with great accuracy the alternation of these wind-currents, and Sidi Ali, in an Arabic work on the navigation of the Indian Ocean, published in 1554, gives the time of commencement of each monsoon at fifty different places. Marco Polo refers to them as follows:—'For in that Sea' [*i.e.* of Mangi or Manzi, 'the eastern sea of Chín'] 'there are but two winds that blow, the one that carries them outward, and the other that brings them homeward; and the one of these winds blows all the winter, and the other all the summer.' The periodical winds just described—namely the two trade-winds, and the south-west monsoon—extend about 30° on each side of the equator.

In the temperate and frigid zones the winds are characterised as variable, since they neither blow in a constant direction, nor are subject to the periodical changes which characterise the winds of the torrid zone. Their direction depends upon the general distribution of atmospheric pressure, and at any given place upon the configuration of the ground.

The barometer stands high at any place—

(1) When the air is cold, for then the lower strata are denser and more contracted than when it is warm.

(2) When the air is dry, since dry air is heavier than moist air.

(3) When an upper current sets in towards a given area, for in this way the lower strata are compressed and an increase of pressure is the result.

The barometer stands low—

(1) When the lower strata are heated, for this causes the surfaces of equal pressure to rise, and the air in the higher regions to overflow; which means that the mass of air pressing on a unit of area at the surface of the earth is reduced.

(2) When the air is moist, for moist air is less heavy than dry air.

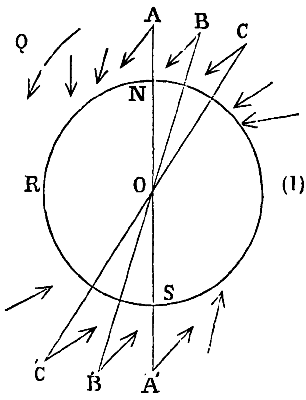
(3) When from any cause the air has an upward movement; for this causes the overflow referred to in (1). From these general principles it is inferred that the highest barometrical readings occur over continents and in high latitudes, and in localities which are characterised by abnormally low temperatures.

Again, when the air over any region is warm and damp it will have a tendency to move upwards, and this will cause the barometer to fall. There are two low-pressure areas due to this cause in the northern hemisphere, one over the Atlantic, and the other over the Pacific.

### Relation of the Winds to Regions of High and Low Pressure.

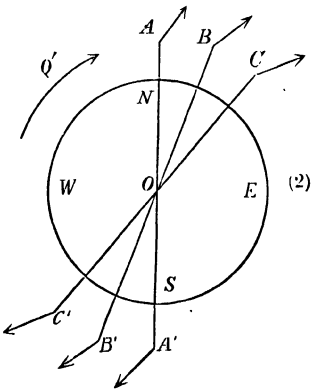
It will be of great assistance in understanding many phenomena connected with the circulation of the atmosphere, if we now state more precisely than has yet been done the relation which exists between the direction of the wind and the areas of high and low pressure. It has already been stated that the wind blows from a region of high pressure towards one where it is relatively low. It would be more exact to say that the wind *tends to blow from a region of high pressure towards one where it is relatively*

*low*; for, owing to the rotation of the earth on its axis, the *actual* direction of the wind is never in the direct line joining the two. In the case of the north-east trade-wind, we have seen that the current flowing from the higher latitudes towards the equator becomes, owing to the cause just mentioned, a north-east wind; and this is only one example of a law which, with appropriate modifications, is true in all cases. We shall now explain what takes place when the phenomenon occurs on a smaller scale. (1) Suppose the area within the circle to represent a region of relatively low barometric pressure, and that the pressure decreases on all sides towards the centre, the air from every quarter will tend to flow directly inwards towards the low-pressure area. We shall suppose the locality represented in the above figure to be in the northern hemisphere. Consider the air at three points, *A*, *B*, *C*, to the north of the barometric depression, and also at *A'*, *B'*, *C'* to the south of it. Were it not for the rotation of the earth, the air from *A*, *B*, and *C* would flow along the lines *AO*, *BO*, *CO* towards *O*, the seat of lowest pressure. But the air at these three points has come from a higher latitude, and is directed towards a point *O* nearer the equator. It will therefore be deflected in the direction of the arrows, since, owing to the earth's rotation, it will have a motion towards the west, relative to the direction of *AO*, *BO*, *CO*. In short, the explanation which is applicable to the north-east trade holds good here. In regard to the air at *A'*, *B'*, and *C'*, the circumstances are the same as those which occur in the case of the winds which pro-



(1)

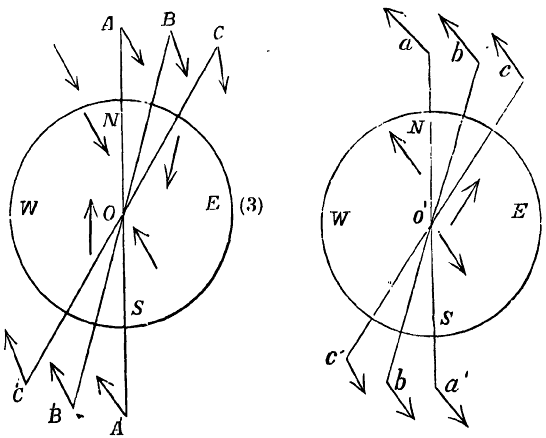
duce the south-west monsoon. For the air at these points has come from a lower latitude, and is travelling towards $O$, a point further north; therefore, relatively to the lines $A'O$, $B'O$, and $C'O$, it has an easterly motion, and will blow from some point between south and west. In a similar manner, all the winds which blow inwards towards the area of low pressure deviate in the same direction from the radial lines. It is easy to see that the result of the action of these currents of air will be to produce a rotatory motion in the mass of the atmosphere surrounding the region of low pressure. The rotation is due to the action of what is known in Mechanics as a couple. From an inspection of the figure it will be seen that the direction of rotation is that of the arrow $Q$, or in the opposite direction to that of the hands of a watch. The winds do not actually describe circles, but a series of spirals round the seat of low pressure. The system of winds round an area of low pressure, of which the above is an illustration, is known as a cyclonic system. When the winds are strong they receive the name of cyclones, and when less severe cyclonic storms.




(2)

(2) We have now to consider the case where the area enclosed by the circle represents a region where the barometer is highest, and let it be supposed that the pressure decreases from the centre outwards. The air will here tend to blow outwards from the centre in all directions. We shall suppose, as before, that the locality is in the northern hemisphere. The air at $A$, $B$, $C$ has come from $O$, a place situated in a lower latitude than $A$, $B$, and $C$; it has there-

fore a motion to the east, relative to the radial lines, *OA*, *OB*, *OC*. At *A′*, *B′*, *C′* the air has come from *O*, situated in a higher latitude than the points themselves, and will have a motion to the west, relative to *OA′*, *OB′*, and *OC″*, the explanation which was given in the case of the north-east trade-wind being applicable here. The result is that the winds will have a rotatory motion round the region of high pressure, the direction being that of the hands of a watch as shown by the arrow *Q′*. The system of winds which circulates round a region of high pressure is known as an anticyclonic system, and around such a region the pressure decreases slowly, and the winds in consequence are light, and radiate more directly outwards than where the pressure decreases rapidly.




(3)

Figures (3) and (4) are intended to represent a system of winds—the former a cyclonic and the latter an anticyclonic system—in the southern hemisphere. In the former the wind is blowing from all sides towards the point of lowest pressure at the centre of the low-pressure area. That which has arrived at *A*, *B*, *C* from the direction of the equator will have a motion towards the east, relative to

these points, and will consequently appear to come from some point between north and west as shown by the arrows at *A*, *B*, and *C*. The wind at *A'*, *B'*, *C'*, having come from places further south, will, like the wind in the south-east trade, be deflected towards the west, and will blow as a south-east wind. The result will be to produce rotation of the winds around the low-pressure region, but the direction of the arrows will show that the rotation is now in the direction of the hands of a watch, and consequently in the opposite direction to the anticyclonic rotation in the northern hemisphere. In figure (4), which represents the anticyclonic system, the wind is travelling outwards in every direction from the seat of highest pressure at *O'*. On arriving at *a*, *b*, *c*, the wind, having come from a part of the earth where the rotation is less rapid, will be in the same position as those winds which produce the south-east trade-wind, and will blow as a south-east wind. Again, the winds which reach *a'*, *b'*, *c'* have come from a region where the rotation is more rapid, and will have a velocity towards the east relative to *a'*, *b'*, *c'*; its direction will therefore be from a point between north and west. The resulting rotation will be in the direction opposite to the hands of a watch, and consequently in a direction contrary to that of an anticyclonic system in the northern hemisphere.

The relation of wind to barometric pressure may be briefly summed up as follows: round an area of low pressure or in the northern hemisphere the wind will circulate so as to have the lowest pressure on its left, or in a direction opposite to the hands of a watch. Round an area of high pressure in the northern hemisphere it will circulate in the direction of the hands of a watch.

In the southern hemisphere the direction of motion will in each case be reversed. Round a region where the barometer readings are low, the wind will circulate in the direction of the hands of a watch, and round an area of high readings in a direction opposite to this. The

principles which have been here enunciated are well expressed in the law known as Buys Ballot's Law, so called from Professor Buys Ballot of Utrecht.

'In the northern hemisphere stand with your back to the wind, and the barometer will be lower on your left hand than on your right.

'In the southern hemisphere stand with your back to the wind, and the barometer will be lower on your right hand than on your left.'

From the above law the distribution of pressure can be inferred where the direction of the wind is known, and conversely from a knowledge of the distribution of pressure the direction in which the wind will blow can be inferred.

With each of these areas of high and low barometric pressure — the anticyclonic and cyclonic systems — a particular type of weather is associated, and it is in this respect that their relations become of the highest importance to meteorologists. Depressions are generally accompanied by unsettled weather, a cloudy sky, dampness of the air and rain. This implies warmth in winter and cold weather in summer. In an anticyclone the weather, as a rule, is fine, the sky cloudless, and the air dry, though fogs are sometimes prevalent. These conditions give rise to cold weather in winter and heat in summer. Mr. Blanford's remarks respecting the relation of Indian weather to these two pressure-systems are so valuable that I here quote his own words :—

'The general prevalence of fine dry weather in the Indian cold season, and of rainy and stormy weather during the summer monsoon, is primarily due to the fact that in the former Northern India is generally for weeks together a region of high barometer, and in the latter of low barometer; and it is in virtue of the comparative stability of these opposite conditions that the opposite characters of the two seasons are so marked. The anticyclone over Northern India in the cold season is, however, not quite stable. Now and then a barometric depression

partly or entirely displaces it; and it is on such occasions that we have the cold weather rains of Upper India. How these depressions originate is at present by no means clear. In some cases they seemed to be formed in North-western India, or even farther South. In others they probably reach India from the West; though in the absence of weather reports from any of the countries that lie in that direction (beyond Quetta) it is impossible at present to verify this. It is, however, certain that when these cold weather depressions travel from the place of their first appearance, they always move in some easterly direction, and thus it is that a spell of rain in the early months of the year begins as a rule in North-western India, and on subsequent days extends to the North-west Provinces, and sometimes though more rarely to Bengal. In the rainy season they are formed either in some part of the permanent depression then existing in Northern India, or more frequently on its outskirts, in the prolongation of its axis over the north of the Bay of Bengal; and their subsequent course is between west and north-west. In the intervals between the monsoons they originate over the seas around India, and more often in the Bay of Bengal than in the Arabian Sea. The direction in which they travel is then more variable, but still more frequently to the north-west or west-north-west.'

Anticyclones are more or less stationary. Depressions, in higher latitudes at least, move over the earth's surface from west to east, the direction of their path, as well as the amount of cloud or rain which accompanies them being modified by the nature of the surface over which they travel. A moist wind, for example, may blow over a level country accompanied by a clear sky, but if it come in contact with a range of mountains, and be forced to ascend, its temperature will sink and the moisture it contains condense into cloud which may fall as rain.

In addition to the general circulation of the atmosphere above described, there are in many parts of the world

circulations of a local character. As an example we have the well-known land and sea breezes, which occur with great regularity in hot countries, though they are not unknown in temperate latitudes. In this case a breeze begins to blow about noon from the sea towards the land, and dies down about sunset. About midnight again a breeze sets in from the land in the opposite direction towards the sea, which in its turn ceases about sun-rise. This phenomenon was formerly explained on the supposition that air was drawn in towards the land from the cooler sea by day, and that the reverse action takes place at night. If this were the true explanation, the sea-breeze ought to start directly from the shore and make its way landwards. It had been observed by Dampier, two hundred years ago, that the sea-breeze begins in the offing —that is, some distance from t e shore—and makes its way gradually to the land, and that the land-breeze comes off from the shore and forces its way out to sea. Mr. Blanford's explanation of the phenomenon in question seems exactly to fit the facts of the case. In considering the general circulation of the atmosphere, we have seen that, owing to the heating of the earth's surface in the neighbourhood of the equator, the air over that region expands, and that the surfaces of equal pressure become distended like the outside of an inflated bladder, and that as the result of this there is an overflow of air from the equator towards the poles. Applying this principle, Mr. Blanford supposes that when the air over the land is heated, and raised in the manner here referred to, the upper strata slide off towards the sea where it is cooler, and produce an increase of pressure at some distance from the land. The air will then begin to flow from this region of increased pressure towards that where the air has been rarefied and the pressure diminished. This explanation is in agreement with what actually occurs, namely, that the sea-breeze commences at some distance from the land, and that it is not a wind drawn in by suction starting with the

particles nearest the heated region and working its way backwards.

At night the atmosphere over the land is cooled on account of radiation from the earth. The air from this cause will contract, and the surfaces of equal pressure will slope towards the land. The air from the sea will then slide down from the sea over the land and push its way out from below as the land-breeze. The sea-breeze is generally a damp wind, being charged with vapour in consequence of evaporation from the sea. The land-wind is dry, and in some places where it prevails is hurtful to men and animals. This is more especially the case in Southern India and Ceylon.

A similar alternation of winds takes place in mountainous countries. About 9 or 10 A.M. the day wind begins to blow up the valleys, freshens till the afternoon, and dies down about sunset. After some time a breeze in the opposite direction blows down the valleys as the night wind. These alternations take place with such regularity that their non-occurrence is known as a sign of the approach of bad weather.

This phenomenon is explained by considering the action arising from the heating of the air by the sun on the lower mountain-slopes during the day. By this means the surfaces of equal pressure are raised, and the air has a tendency to blow towards the mountains, along the upper valleys. This action continues until the heating effect of the sun is withdrawn. At night, when the temperature of the air in the valleys sinks, it will undergo contraction and produce a partial vacuum. This causes a current of air to set in from the mountain-tops, flowing down the valleys towards the plains. This breeze will last all through the night.

*Storms.*—The subject of storms can only be touched upon very briefly here, and the few particulars now set down have reference more particularly to India. Any violent wind which is attended with rain, hail, or snow, is named

a storm. In India the same term is applied to dust-storms, which frequently occur without rain. With reference to the apparently rainless dust-storms which take place in Northern India and the Punjab, Mr. Blanford observes that it is difficult to account for the cool wind which blows during the progress of the storm, and for the cool atmosphere by which they are succeeded, except on the supposition that there has been a deposition of rain in the cloud overhead; but that this rain may have been re-evaporated before reaching the surface of the earth. In the North-west Provinces and the Eastern Punjab, dust-storms are not unfrequently accompanied with some rain. In Bengal, where the atmosphere is more moist, a dust-storm is mostly the prelude to a nor'-wester, and is followed by heavy rain. Atmospheric disturbances of this class are limited in extent, and of a transient nature. On their approach, the barometer at first rises rapidly, and this rise is succeeded by much irregular oscillation. Before a cyclone the barometer falls steadily, and its different action in the two cases is thus a guide as to the nature of the storm to be expected. For a few days before the occurrence of a dust-storm or a nor'-wester, the barometer is generally somewhat below the average for the time of the year, but the depression is never very great. Both dust-storms and nor'-westers, as a rule, occur in the afternoon or evening, towards the close of a warm day, with little wind or a damp one from the sea. Before the outbreak, the air is unusually calm and sultry. The simplest form of the dust-storm is that of a tall aërial column of sand moving onwards, and drawing into itself, as it whirls round in its course, dust and other light bodies within the sweep of the strong currents of air which blow along the surface of the ground. The conditions for the occurrence of a nor'-wester are that the lower portion of the atmosphere be warm and damp, and that immediately above, at a height perhaps of several thousand feet, be dry and cooler. The cloud is formed by the ascent of the damp air penetrating the

colder air above, as this causes the moisture to condense. The storm almost always comes from the west or north-west. These storms do not indicate any important disturbance of the atmosphere, although they may be violent locally.

*Cyclones and Cyclonic Storms.*—The atmospheric disturbances known as cyclones and cyclonic storms do not differ from one another in their constitution, nor in the mode in which they originate. The cyclone is regarded as an intensified form of the cyclonic storm. The latter term is applied to the comparatively mild disturbances which take place during the summer monsoon, and to those which bring the winter rains of Northern India. In a cyclone the wind blows with destructive violence. The storm is generally associated with torrents of rain, electrical disturbances of the atmosphere, and not unfrequently by the storm-wave, which is the most destructive of all its accompaniments. When a cyclone advances against a low alluvial coast, the sea sometimes rises in a great wave which sweeps over the land. In the cyclone of October 5, 1864, the water in the estuary of the Hugli rose about 16½ feet above the highest spring-tide level, submerging the low-lying lands, and causing great loss of life. Much greater destruction was caused by the Backergunge cyclone of October 31, 1876. The marks on the trees showed that the water had risen to heights varying from 10 to 45 feet; and the loss of life is believed to have exceeded 100,000 persons. It has been already stated that the conditions under which both a cyclone and a cyclonic storm take place are, that the barometer over a limited area of a circular or oval form should stand lower than it does over the region lying beyond this. The air rushes in from all sides towards this low-pressure area, and as we have already seen, it does not blow directly towards the centre of the depression, but has a rotary motion round it. The rotatory motion is not circular, but the curves described are spirals converging on the centre. The

direction of rotation is in the opposite direction to the hands of a watch in the northern hemisphere, and in the southern hemisphere in the same direction. The force of the wind varies with the steepness of the barometric gradient, consequently, when such a storm is approaching, the wind blows more strongly the more rapidly the barometer falls. In the centre of the storm the air is calm, although the barometer in that position marks its lowest. In the centre of a cyclone the barometer readings are as much as one inch, and sometimes two, below those which are recorded a few hundred miles off. In a cyclonic storm the depression does not in general go beyond a few tenths of an inch. The central depression is larger and not so well defined, but it is often accompanied by very heavy rain. Although the cyclonic storm is the milder of the two types, it is, nevertheless, more lasting than the cyclone, which is rapidly broken up when it encounters any obstacles which oppose it on land.

Cyclones occur only in the intervals between the monsoons, or perhaps more frequently at their commencement or close. Cyclonic storms are of frequent occurrence during the whole period of the summer monsoon, and also during the winter months in Northern India.

# THE VEGETABLE KINGDOM

# THE VEGETABLE KINGDOM

THERE is perhaps scarcely any science that can be more within the reach of the means of the humblest student than the science of botany. A pocket lens, a sharp pen-knife, and a book descriptive of the flora of the district or country where one lives will form a sufficient equipment to enable the student to name and classify whatever plants he may meet with in his rambles in search of them.

It is by no means intended to imply that finding out the names of plants and being able to classify them constitute the whole science of botany. The truth is that many of the problems in connection with classification are most abstruse, so much so that even now the most recent and generally received system of classification can only be considered provisional. This is especially the case in regard to the lower forms of vegetable life. The life-history of many of the most minute and lowly plants is but imperfectly known, owing to their extreme minuteness and the different forms which they assume at the various stages of their life-history.

This, however, does not detract from the pleasure which any one may derive from being able to describe and name any flowering plants which are to be found in any country at certain seasons.

The dependence of mankind on plants is too obvious to equire mention.

To a large extent the vegetation of a district determines its character; for without plants no landscape would

possess any particular attractiveness, and every one knows the depressing effect produced by a barren, treeless waste. The contrast between this and fields rich in pasture has occurred to every one; and a well-wooded country never fails to please the eye of the observer.

Mighty forests, teeming with life, have a powerful influence on the imagination; and the value of forests both as regards their effect on climate and their economic importance has been so thoroughly recognised, that in the case of India stringent measures have been adopted for their preservation.

Some knowledge of plant life also enables one to guard against the evil and often fatal effects produced by eating poisonous fruits and poisonous fungi.

Some of the lowly organised flowerless plants are man's most deadly and insidious enemies. These from their excessive minuteness are quite invisible to the naked eye; but as more detailed reference is made to them under Bacteria, nothing further need here be said about them.

Before proceeding further, it will be necessary to give a brief account of the different parts which go to compose the complete flowering plant. The reader who desires a full and detailed account of the different organs of the flowering and flowerless plants will find this in any standard text-book of botany.

We will take any full-grown flowering plant and begin with the root.

The root may be called the descending portion of the axis.

The ascending portion of the axis is usually supplied with leaves, flowers, and green colouring matter, whereas the root is usually devoid of these.

The root generally penetrates into the soil and fulfils a double function.

It is by means of the roots that the plant is attached to the earth and prevented from being blown about by the winds.

In the case of large forest trees, the far-spreading roots have an immense power of resistance. The large surface of a giant tree in full leaf has to endure an enormous lateral pressure during a high wind, and even hurricanes may fail to uproot a large tree, which they may snap asunder. Not only does the root by penetrating the soil attach the plant to the earth, but it absorbs nourishment from the soil for the support of the plant. The root, therefore, fulfils a double function.

The root is at first furnished with a conical hood of cellular tissue, *i.e.* tissue consisting entirely of cells or little closed bags made up of an outside wall and contents.

The root cup is well seen in some kinds of water-plants, such as duckweed.

There are plants whose roots do not descend. Certain plants hang from the branches of trees, and though they have roots these roots never penetrate the soil. Plants of this kind are called Epiphytes (Greek *epi* upon, and *phyton* plant). Aërial orchids, which grow in warm and moist parts of India and other countries, are attached to branches of trees or other kinds of support, and their roots hang down from the peculiar stems and are very soft and delicate at the tips.

It must be borne in mind that there is no absolute distinction between root and stem; for some trees have roots which form lateral buds, viz., *Pyrus japonica*, *Maclura aurantiaca*, and many others.

This is quite in accordance with the fact, that in the organic world different organs frequently shade into one another.

The true root of the plant in its earliest state of existence, that is, as it exists in the seed prior to germination, is the downward prolongation of the axis.

In the case of the division of flowering plants called Monocotyledons (Greek *monos* single, and *kotyledon* seed-leaf), and in such so-called flowerless plants as ferns, the lower end of the axis soon ceases to grow and the roots

which supply these plants with nourishment are really lateral growths. The roots of plants are variously named. Sometimes the branches of the roots are small, and the central axis thick and of considerable length. This kind of root is named a tap-root, and may be well seen in the carrot.

In the turnip, beet, and other plants, where this organ is developed in such a manner as to serve as a reservoir of nutriment, the root is tuberous.

Many roots are fibrous; this may be well seen in grasses.

The perennial woody forms of fibrous roots are very characteristic of shrubby Dicotyledons (plants with two seed-leaves).

Leaves are of two kinds, namely, foliage-leaves and flower-leaves.

A leaf is generally a broad flat horizontal surface. It is usually thin, and can be divided by a perpendicular plane, the median plane, into two similar halves.

When the leaves are what is called symmetrical, the parts into which they are divided are counterparts.

If one of these parts were held in front of a looking-glass, the reflected image of this part would represent the part from which it had been separated.

Many leaves, however, cannot thus be divided. When this is the case they are said to be unsymmetrical.


Begonia Leaf.

The tropical plant Begonia affords an excellent example of an unsymmetrical leaf.

The leaves of the spruce are not flat but needle-shaped.

In rushes and many species of stone-crops the leaves are cylindrical or round.

The leaf consists of three parts, viz., the sheath, the stalk or petiole, and the lamina or blade. The sheath encloses the stem at the insertion of the leaf, and has a tubular or sheath-

like form. It is well seen in grasses and such plants as celery, corn, parsnip, carrot, and other plants belonging to the *Umbelliferæ* [Lat. *umbella* (*umbra* shade) little shade, and *ferre* to bear].

The leaf-stalk is narrow, and has a semi-cylindrical or prismatic form, bearing at its end the expanded leaf.

When the stalk is flattened and resembles a leaf, as in the case of the Australian acacias, it is termed a phyllode (Greek *phyllon* a leaf, and *eidos* form).

Many leaves have no sheath, but only the stalk and the blade. This is the case in the maple and gourd.

The leaves of the grasses have no stalk, but only sheath and blade.

The blade is often the only part present, as in the tobacco plant and tiger-lily. Small appendages, looked upon as belonging to the sheath, are frequently present, and are termed stipules (from Lat. *stipula* blade). Leaves having these appendages are called stipulate, and leaves devoid of them are ex-stipulate (from Lat. *ex* privative, without, and *stipula* blade).

A few plants, such as grasses, have a small outgrowth from the inner upper surface of the leaf at the part where the sheath and the blade are joined. This outgrowth is named a ligule (from Lat. *ligula* a little tongue).

If a leaf is carefully examined it will be found that the internal tissues differ in character. The fundamental tissue is generally green, and is named the messophyll (Greek, *mesos* or *messos* middle, and *phyllon* leaf.)

It will be seen that bands run through the fundamental tissue called the veins of the leaf. These veins consist of what are termed fibro-vascular bundles. They endure longer than the fundamental tissue, and may frequently be seen after the leaf is withered and dead, forming the skeleton of the leaf.

The arrangement of the veins or fibro-vascular bundles is characteristic of large groups of plants.

In the narrow linear leaves of grasses the stronger veins

run almost parallel. In broad leaves, such as those of the lily-of-the-valley, the veins curve, but do not form a network of tracery as in oaks and other Dicotyledons. The margin of leaves is frequently divided, but the technical terms used in describing such leaves can be found in any text-book of botany. They may either be simple or compound. A simple leaf consists of a single lamina, however much it may be divided, provided the divisions do not extend to the central vein or mid-rib. A leaf is compound when, besides the principal leaf-stalks, a number of lateral leaf-stalks exist bearing at their ends laminæ. The leaves of many plants are compound. The sensitive plant (*Mimosa pudica*) furnishes an excellent example of the compound leaf.

The characteristic colour of foliage leaves is green, and they are so arranged as to receive as much sunlight as possible. The importance of the plant receiving a good supply of light will be referred to when treating of the growth of plants. It is as true of plants as of animals that the organs most suitable for their surroundings are so arranged as to be most advantageous to the individual. Had leaves been placed vertically they would only have received diffused sunlight instead of the direct rays of the sun. No vegetable life could exist but for the sun, as plants not only require light but heat as well.

When the foliage leaves are small they are very numerous, as may be seen in conifers; and when these leaves are large they are not nearly so numerous, as, for example, in the sun-flower.

Sometimes leaves may consist of scales. These scales are always found on stems growing under-ground, as in the onion; but they sometimes occur on stems growing above-ground.

Such plants as *Orobanche* and *Neottia* have no other kind of leaves except scales. More detailed reference will be made further on to the plants having only leaf-scales.

The leaves are developed very near the apex of the growing stem.

The portions of the stem which lie between the leaves are termed the internodes, and the parts where the leaves are inserted are termed the nodes.

Leaves are arranged in various ways, intimately connected with the order of their development. They may be developed so that three or more are at the same level on the stem; this arrangement is termed a *whorl.* Or they may be developed singly; this arrangement is termed *scattered.* For a full account of the various leaf-arrangements any text-book on botany may be consulted.

We have here merely referred to some of the more obvious arrangements of the leaves.

Certain leaves possess a remarkably abnormal shape; for examples stone-crops have cylindrical leaves; if the leaf of an agave is cut across, the section is triangular; leeks, again, are tube-shaped; the central cavity being due to the rapid growth of the outer tissue. These leaves are all juicy or succulent; certain other leaves are leathery, that is, they have a harder and thicker epidermis than the succulent leaves, and may last for several years, as, for example, in the holly and box.

Spines and tendrils are modifications of leaves, or parts of leaves. The tendrils are formed out of entire leaves, mid-ribs, leaflets, or stipules. Both spines and tendrils, however, may be modified branches of the stem.

In buds the leaves are packed or folded in various ways. This is best seen before the buds are opened in spring. The buds may then be pulled carefully to pieces, and in this way the manner in which the leaves are folded can be studied.

We now come to the flower.

Flowers consist of leaves modified in different ways.

Take, for example, the flower of the orange. The flower will be seen to be borne on a short branch which serves as the stalk, and is distinguished by the name of peduncle (from Lat. *pedunculus* little stalk). It will be seen that there are no internodes between the flower-leaves.

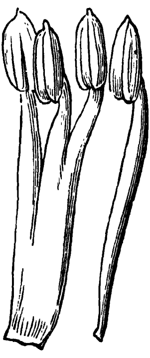
The lowest and outermost part of the flower forms a little cup having upon its margin fine small teeth, indicating the number of leaves which are joined together so as to form the cup or calyx.

These leaves are named (from Lat. *calyx* a covering; Greek *kalyx*, from *kalyptein* to cover) the calyx-leaves, or sepals (French *sépale*). Although they are united in the flower of the orange, they are often separate in other plants.

In the sacred Lotus or Padma or Pudma of India the sepals are separate or free. The leaves immediately inside the calyx are usually five in number. They are erect, or only slightly curved, and do not grow together like the leaves of the calyx. They are white and wax-like. These leaves form together what is termed the corolla, and the separate leaves of the corolla (from Lat. *corolla* a little wreath) are termed petals (from Greek *petalon* leaf). In the case of the orange the petals fall early away.

If the calyx and petals are carefully removed, the next part of the flower can be observed.

This series of flower-leaves differs very much in structure from both sepals and petals. Each leaf of this series consists of a linear stalk-like portion, bearing an upper somewhat long and grooved head. The stalk is named the filament, and the oblong head is named the anther (Greek *anthos* a flower). The stalk and the head together form what is called the stamen [Lat. *stamen* [Greek *histanai* to stand] fibre; literally, the warp in the upright loom of the ancients]. The stamens of the orange are rather shorter than the petals, and are united to each other.



Stamens of the Orange.

When the anther is mature, each of its grooves splits near the edge, and allows the fine powdery granules which fill the anthers to be removed by insects or by other means.

This fine powder is named the pollen, and each of the granules composing it is named a pollen grain. If the stamens are now removed the centre of the flower alone is left.

If the lower part of the centre of the flower be cut across, it will be found to be divided into a large number of cavities containing the minute rudiments of future seeds. It will be seen that there are ten cavities, though they may vary in number. The central organ of the flower is named the pistil (from Lat. *pistillum* pestle). The pistil is usually composed of united leaves.

Ovary of the Orange.

The separate leaves of the pistil are termed carpels (from Greek *karpos* fruit). These leaves are sometimes not combined as they are in the orange. The style belongs to the carpel, and varies considerably in length, as well as in stoutness, in different flowers. Although the carpels may be united, the styles may remain completely separate, as, for example, in the pink, or, as in the fuchsia, they may be combined into a single rod.

The pollen grains (Lat. fine flour) contained in the anther are composed of very rich protoplasm (Greek *prōtos*, first, *plasma* formative matter), which usually has in it small drops of oil and small starch granules. The pollen grains are bounded by two principal layers, an outer and an inner; the purpose of the outer layer (which is often provided with thickenings in the shape of knots, spines, etc.) being to preserve the contents of the grain from evaporation.

The inner layer is living and capable of growth, and at certain spots it possesses thickenings which project into the protoplasm. Opposite to these the external cuticle is frequently thinner, and this eventually is lifted off as a sort of lid, and through this the inner substance can grow out, and is then named the pollen tube.

When the anther lobes open to discharge their pollen grains, these grains are completely developed.

The grains fall on the part of the ovary named the stigma (Greek *stigma*, a puncture made with a sharp instrument; here it means a sharp point or apex) and the inner layer begins to force its way out. The tube is produced from the contents of the pollen grain, and is formed by growth just as any other part of the plant. The pollen tube passes down to the ovules, the route depending on the length of the style. The time taken by the pollen tube to reach the ovary may amount to a few hours in certain plants, whilst it needs months in others. It is necessary that at least one pollen tube should enter the mouth of the ovule before it can develop into a seed.

The seed, when mature, contains the embyro plant. For fuller information in regard to the successive stages of the growth of the embyro plant, and the fertilisation of the ovules, any modern text-book on botany may be consulted. For the leading facts of botany, put in a concise and popular manner, see *Botany*, by Mr. Bettany (in Ward, Lock, & Co.'s *Science Primers for the People*), which contains numerous illustrations.

It is not possible for an ovule in numerous cases to be fertilised by pollen from stamens that grow near it in the same flower.

It not unfrequently happens that a flower possesses stamens and no pistil, or a pistil and no stamens. Flowers of this kind are technically termed diœcious (Greek *dis* twice, and *oikia* or *oikos* place of abode), if the male and female flowers are on different plants. The flowers of such plants as oaks and birches are male and female, but are borne on the same plant, hence termed monœcious (Greek *monos* single). The flowers that contain stamens only are called male flowers, and those containing pistils only are named female flowers.

The oaks and birches, as has been stated, have both the male and female flowers on the same plant, though in other

cases the male flower is borne on one plant, and the female flower on another.

In cases like these the wind carries the pollen from one plant to another. In wind-fertilised flowers the flower is usually produced prior to the foliage leaves, or at least before the plant is crowded with leaves.

These plants produce an immense amount of pollen.

Besides the transference of pollen by the agency of the wind, insect agency plays a very important part. These insect-fertilised plants are much more conspicuous than those fertilised by the wind.

There are numerous natural contrivances in plants to prevent self-fertilisation, as this process of self-fertilisation is far less effective in producing seeds than when the ovules are fertilised by pollen from another plant of the same species.

In some plants the stigma is mature before the anther, and in such a case the pollen must be brought from a flower that has bloomed a little earlier than itself.

The subject of the fertilisation of plants has a literature to itself. Since the time of the publication of Darwin's observations on the fertilisation of orchids, and his experiments on the effect of self- and cross- fertilisation, many observers have devoted their attention to this most remarkable subject.

An account of his observations will be best understood by those interested by reading the works of Darwin himself, as no epitome can give a proper idea of the patience and remarkable skill he employed through successive years. The German botanist and traveller Müller has also published many of his observations on this subject.

For those who desire to read a popular and small handbook on fertilisation of plants, in reference to the contrivances which plants adopt to secure cross-fertilisation, such a book as that published in *Nature Series*, and written by Sir John Lubbock, will supply them with sufficient information.

Nothing has been said about carnivorous plants, or plants such as the Venus-fly-trap, which entangle insects in their leaves and absorb the nutrient substance contained in their bodies.

This subject has also, since the publication of Darwin's *Carnivorous Plants*, a literature devoted to itself.

### The Tissues of Plants.

*Tissue* is a word meaning texture, structure, or kind of material. In plants there is cellular tissue, woody tissue, etc. It is connected with the Latin verb *texere* to weave, and is applied as a generic term to the different kinds of fundamental vegetable units which being connected together form part of a plant. The term is inapplicable to plants composed of only one cell; but if two cells formed out of one instead of becoming separate continue to grow together, and if these two cells further divide, and the four cells thus formed still remain attached and so on, a species of tissue is formed termed cellular. If these divisions have taken place parallel to each other a cellular thread is produced. If, however, the divisions take place in two directions at right angles to each other, a sheet or surface of cells is formed.

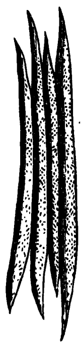
Suppose the divisions in directions at right angles to each other be supposed to take place in planes perpendicular to the plane of the paper, then other divisions may be supposed to take place parallel to the plane of the paper; by these different directions in the mode of dividing a solid mass of cells is formed. All cells are not the same; water-plants, for example, can always absorb liquid by their surface membranes, through their excessively minute invisible pores.

When two or more cells are organically united with a partial extent of party-wall between them, the power of transmitting liquid through the cell membrane remains. When, however, there is a solid aggregation of cells, the

inner cells can only obtain nourishment which has come to them after passing through other cells. If we consider plants which are partly surrounded by soil and partly by air, we find the surface membrane altered in texture for the purpose of preventing excessive evaporation, and the necessary nourishment is received through special modifications of the surface; but here also the inner cells obtain their nourishment through the outer cells. Owing to this one would naturally suppose that the inner cells of plants will always be different from the outer.

### The Principal Kinds of Tissue.

The tissues of the higher plants may be considered as falling under three main series: (1) those of the ground work; (2) those which seem to strengthen the structure; and (3) the epidermis which serves as a protective cover-



1 Fibrous tissue.

2 Fibrous tissue.

ing. In the lower Cryptogams there is no distinction of tissue, but the three series mentioned exist in ferns and all flowering plants. In simple cellular tissue the cells are nearly of the same dimension in all directions; but when the cells undergo considerable elongation the tissue is termed fibrous.

'Vessels' may be considered a distinct tissue, since the

cells composing them are not only elongated, but portions of the partitions between a number of successive cells disappear during growth, and a continuous cavity is thus formed.

When the cells have attained their fully organised form, the tissue is termed permanent.

The cells forming a tissue have naturally a common wall between them, but very often spaces are formed between adjacent cells, owing to the separation of the common wall into several points. These spaces contain either air or liquids.

### Vascular Tissues.

[Lat. *vas* vessel, *vasculum* little vessel, therefore 'vascular' means 'containing vessels.']

These tissues are present in almost every part of the higher plants, and generally include simple cells besides fibres and vessels. There are two principal modifications of these tissues, one in which the thickening layers are woody in character, and the other in which the thickening layers are either soft or very little developed. The shapes and varieties of the thickenings of the cells are numerous, and as a consequence the composition of the vascular bundles is frequently complex and varied in character.

The composition and mode of growth of these bundles are characteristic of the kind of plant. In palms and ferns their growth is complete after a part of one season, and the growth can only take place at their ends, and their thickness does not continue to increase.

In Dicotyledons, such as cone trees, there is a layer of tissue which passes completely across the vascular bundles, and is capable of dividing and producing new cells, fibres, and vessels in successive seasons. These vascular bundles, with the layer of dividing tissue, are said to be 'open,' while the bundles in palms, ferns, and other Monocotyledons are said to be 'closed.'

## STRUCTURE OF WOOD.

In general it is the vascular bundles nearest the centre of trees which become woody. The vessels contained by the bundles have at first spiral or ring-like thickenings, and the parts of the bundles which are continued into the leaves generally only contain vessels with a spiral thickening.

The vessels, formed in successive years during the outward growth of the wood, are generally thickened in such a manner as to cause them to have the appearance of being covered with small dots or pits when seen under the microscope. A large proportion of the wood is made up of fibres with pointed ends, which dovetail between one another, that is, the ends are closely packed beween one another; and the fibres extend lengthwise in their bundles.

These woody fibres also undergo thickening, but are devoid of any characteristic markings. Short round or oblong cells also occur in the wood, and these become more or less thickened. The woody fibre of cone-bearing trees, such as firs, is characterised by remarkable double-bordered pits. The vessels in ferns are nearly all characterised by thickenings of a scalariform or ladder-like appearance. From the fact that these bundles contain both vessels and fibres, they are usually termed fibro-vascular bundles.

These bundles at first consist of similar cells combined without any intercellular spaces. This form of tissue has been termed procambium (Latin *pro* before, and *cambire* to exchange—recent Latin *cambium*, meaning nutriment or nutrient layer). The procambium cells are transformed into what are called cambium cells. This is the name given to the cells which are permanent and remain active in an open vascular bundle. From these cambium cells all the different tissues which make up the bundle are developed. On the inner side of the layer of cambium

cells new cells are continually being formed, and these by variations in thickening and in mode of growth become converted into the elements of the wood; on the outer side the cells that are formed are eventually converted into the different elements which constitute the bast.

Bast is the portion of the vascular bundle whose cell-walls are for the most part soft. In woody plants the bast is usually found near the circumference of the stem.

When the bark is stripped off a tree, the region of the cambium appears as a glistening surface, and just outside this surface is the bast, and this, together with the *epidermis* (Greek *epi* on, and *derma* skin), and what may remain of the original cutis, constitutes the bark.

A vessel is frequently present in bast, which is termed the 'sieve-tube,' owing to certain parts of its walls being perforated like a sieve. The sieve-tube retains its protoplasm in an active condition, and the perforations admit of communication between the adjacent cells. It is an established fact that albuminous substances cannot pass through cell membranes; but the perforations which are usually at the ends of the sieve-tubes allow of the passage of the albuminous substances.

The chief constituent of the bast is the fibres, which have flexible walls, and are employed in the manufacture of matting, etc.

Besides the sieve-tubes and fibres, simple cellular tissue is also found in the bast.

It will be seen from what has been stated that vascular bundles, either open or closed, form a constituent part of the tissues of the higher plants, and those bundles are at first surrounded on all sides by the fundamental tissue from which they are formed. This ground tissue contains active protoplasm. The innermost tissue of this description is termed the pith, which contains no green granules, and the protoplasm which the pith-cells contain is frequently very full of water, besides containing granules of starch and other nutritive substances.

It has been stated that woody fibres and vessels are produced through modifications which the ground-tissue undergoes ; but besides the vascular bundles, ground-tissue is nearly always found in young stems, and frequently in old ones. These cells of the ground-tissue contain green granules, and are found outside the vascular bundles. The tissue of leaves is for the most part made up of cells of two kinds of this tissue. They are generally arranged vertically, or at right angles to the surface, being packed together closely in rows. The groups of cells beneath these are more rounded, having branches which touch each other and enclose air spaces. This is termed spongy tissue. The tissue of which a nutshell or plum-stone is composed is indurated ground-tissue.

*Secretions.*—It is in the ground-tissue where the materials formed by plants, not for their own food, but as products manufactured in these wonderful laboratories, the cells, are for the most part secreted. Some of these products are of great commercial value. These secretions may be classed as gums, resins, oils, balsams, and milky juice, termed *latex*. Gums are formed in great abundance in acacias and cherry-trees ; essential oils in St. John's-worts, oranges, etc. The latex of the poppy yields opium, and caoutchouc or india-rubber is furnished by many of the spurges.

*Protective Tissue.*—This name is given to the outside layer of cells, which are usually flattened and adhere by their edges. The outer membrane of these cells undergoes a change by which they become capable of preventing either the ingress or egress of water, and thus prevent the rapid drying of the delicate cells beneath. This change is known as the transformation into cuticle. For a fuller account of this and other tissues special treatises on plant structure should be read.

Reference should here be made to openings in the epidermis termed stomata (Greek *stoma*, plural *stomata*, meaning mouths). These minute openings admit air into the cavities of the leaves, as well as into the cavities of

many stems, and are guarded each by a couple of cells termed *guard-cells*, these containing active protoplasm and green granules. They are formed of a piece divided off from a single cell of the epidermis. Seen through the microscope 'they resemble a couple of curved sausages placed together so as to enclose a space, which is the opening of the stoma or little mouth.'

The number of these openings varies in different plants. In the rhubarb there are on the under side of the leaf as many as seven thousand to the square inch, while in the turnip there are as many as half a million to the square inch. Succulent leaves have not so many openings, since the moisture is retained in leaves of this character. Floating leaves have the openings entirely on the upper side, while submerged leaves are destitute of stomata; the epidermis, however, remaining soft.

The epidermis which covers root-hairs has no openings, but instead in almost all land plants it possesses special hairs which absorb moisture from the soil.

When tissue no longer contains protoplasm, it is said to be dead.

### Structure of Stems.

The simplest kind of stems contain no vessels; but only a mass of cells, as, for example, mosses. The higher Cryptogams, however, such as ferns, have vascular bundles in their stems. They are few in number in the stems of ferns, and the greater number of the vessels have ladder-like thickenings.

The stems of Monocotyledons may be likened to long thin rods lying side by side. They, like the bundles of ferns, are complete in their first season of growth.

In Dicotyledons the bundles are open, and capable of indefinite increase. The arrangement is constructed on a concentric plan. For an account of the structure of the stems of the various classes of plants, any recent text-book on botany may be consulted.

The mode in which flowers are arranged is termed the inflorescence. The flowers may be solitary, as in the lily, or axillary, when, as in the moneywort, the flowers grow from the axils of the leaves.

The inflorescence of the lily-of-the-valley, for example, is termed a raceme; other arrangements are named a corymb (Gr. *korymbos* the 'cluster' of the ivy flower), and others an umbel (Lat. *umbra* shade, *umbella* little shade), and so forth. These will be found explained and illustrated in every text-book.

### The Physiology of Plants.

Plants like animals require food. Deprived of the elements necessary for their sustenance and nutrition, plants would wither and die of hunger.

All living plants contain a considerable quantity of water. This compound forms not merely the principal constituent of the cell-sap, but also exists in the cell-walls, and in the protoplasm (Greek *prōtos* first, and *plasma* formative matter), and indeed in all organised structures. It is characteristic of all organised structures to have minute particles of water interposed between the particles of solid matter of which they consist.

If a plant is placed in a hot-air oven and heated to from 100° C. to 110° C. all the water will be expelled. And if the plant is carefully weighed before and after it has been heated, it will be found to have lost weight. The weight lost is equal to the amount of water that has been expelled by heat.

The amount of loss is very different in different plants; ripe seeds dried in the air contain from 12 to 15 per cent. of water; herbaceous plants 60 to 80 per cent.; and many water plants and fungi as much as 95 per cent. of their weight.

The residue which gives off no more water at a heat of 100° C. consists of a great variety of chemical compounds. These are partly organic, that is, they are compounds of carbon with other elements, and partly inorganic. These

organic substances (with the exception of the salts of oxalic acid, or the oxalates) all contain hydrogen.

Some of the organic compounds consist of two elements only. Many of the oils found in plants consist of carbon and hydrogen only; but by far the greater number of the organic compounds contain more than two elements.

For example, cellulose, starch, sugar, and the vegetable acids contain carbon, hydrogen, and oxygen in combination. The albuminous substances consist of carbon, hydrogen, oxygen, nitrogen, and sulphur; in other bodies which contain nitrogen (as asparagin), and many alkaloids there is no sulphur; from the alkaloid nicotine existing in the tobacco plant oxygen is absent.

The organic compounds (compounds containing carbon) can generally be resolved into volatile products. The products are chiefly carbonic acid, water, and ammonia. This is effected by exposure to a high temperature with free access of air, in order that the constituents of the air, namely, oxygen and nitrogen, may combine with the elements composing the plant. There is always a residue after combustion. If the combustion has been complete the residue is white, if incomplete it is a grey ash.

The sulphur contained in the plant is during combustion converted into sulphates, and appears in this form in the ash, and the carbon dioxide formed during combustion combines with some of the inorganic substances and forms carbonates. The various elements found in the ash are by no means useless and accidental; for it has been experimentally proved that certain inorganic elements are necessary to the life of the plant; they form in fact part of the food of the plant.

The elements needed to form the organic compounds are carbon (always present in living organised bodies whether animal or vegetable), hydrogen, oxygen, nitrogen, and sulphur.

Secondly, the substances forming inorganic bodies are phosphorus, potassium, calcium, magnesium, iron.

Other elements are found in the ash of many plants, though they are not to be regarded as essentially necessary to the nutrition of the plant.

The following elements have been detected in the ashes of plants, in varying amount:—sodium, lithium, manganese, silicon, iodine, bromine, and sometimes (though rarely) aluminium, copper, zinc, cobalt, nickel, strontium, and barium.

Iodine exists in large quantities in certain sea-weeds; aluminium is an essential constituent of clay.

It is also certain that fluorine exists in vegetables, for it is found in considerable amount in the dentine of animals which are strict vegetarians. Iodine and bromine are the only elements above enumerated that are not metals. Fluorine is also a non-metal, and has perhaps never been isolated, owing to its remarkably strong chemical affinity for other elements.

The chlorophyll-bearing plants derive all their carbon from the atmosphere. This exists in the atmosphere in combination with oxygen, and forms the compound termed carbonic acid gas or carbon dioxide. In comparison with the essential constituents of the air, namely, oxygen and nitrogen, it occurs in small quantities; but it plays a most important part in the economy of plant life.

It is only under the influence of light that the chlorophyll can act on the carbon dioxide. It may here be remarked that carbon dioxide is an exceedingly stable compound, and therefore not easy to decompose. Its existence in the atmosphere is due to the chemical process termed combustion or burning. This process may either be rapid and attended with the evolution of light and heat, or it may be slow and not attended with the evolution of light; though the same amount of heat is always evolved by the oxidation of the same amount of carbon, whether the process is slow or rapid.

An immense amount of carbon dioxide is given off from furnaces; and besides both animals and plants exhale

carbonic dioxide in the process of respiration. Were it not that plants decompose much more carbon dioxide than they exhale, the air would contain too much of this compound, and would therefore be unsuitable for the respiration of animals. The balance is maintained by the chlorophyll-bearing plants. The carbon dioxide is decomposed by plants, and part of its oxygen is restored to the atmosphere, whilst the residue combines with the elements of water, or oxygen and hydrogen, to form organic compounds. These compounds, consequently, contain carbon, hydrogen, and oxygen; and since part of the oxygen is restored to the air, the organic compounds formed in the cells of the plant must contain oxygen in a smaller proportion than it exists in the carbon dioxide which is decomposed.

It is known that nearly all the constituents of the food of plants contain the maximum proportion of oxygen, and since the products formed within the plants are poor in oxygen, it is evident that in the process of nutrition the plants evolve considerable quantities of oxygen.

The first chemical compound that can be detected as a result of this process in most plants is starch. This is a complicated compound containing some multiple of the weight of six atoms of carbon, every six atoms of the carbon being combined with as much hydrogen and oxygen as would form five molecules of water. The starch is found in the chlorophyll-corpuscles in the form of small granules; grape-sugar is sometimes formed instead of starch. This process cannot go on unless the plants are supplied with light, and a certain amount of heat. When plants are grown in the dark no oxygen will be given off, and no formation of starch takes place. The rays most effective in promoting this process are termed the yellow rays of the spectrum, or the rays between the orange and green. The presence of chlorophyll is needed for the performance of this function; but about the exact part which chlorophyll plays there appears to be very considerable doubt.

Certain plants, such as dodder, orobanche, and monotropa, possess no chlorophyll, and are therefore unable to form starch or other compounds whose formation depends upon its presence. The starch formed in the chlorophyll corpuscles does not necessarily remain as starch, but constitutes, as it were, the raw material from which all the other compounds are formed. The nitrogen taken up from the soil by the roots, and the oxygen obtained from the atmosphere, in combination with carbon, take part in this process. The process is termed Metabolism (Greek *metabole* change, from *metaballein* to turn over).

The exact nature of the process that goes on in cells, which results in the formation of most of the remarkable chemical compounds found in plants, is from the nature of the case very imperfectly known. The poisonous properties of numerous fungi, and the deadly alkaloids found in such plants as the poppy, tobacco plant, monk's-hood, etc., are the results of some of the most remarkable chemical processes which occur during the process of growth and alteration of tissues.

A full account of these will be found in books treating of the medicinal uses of plants.

## Reproduction of Plants.

Plants are reproduced in various ways, as, for example, by bulbils, that is, buds which become separated from the parent plant, and produce new and independent plants. Such bulbous buds are found in the axils of the leaves of *Lilium bulbiferum*, and in the inflorescences of species of *Allium*. A similar mode of reproduction is effected by certain stems, especially by underground rhizomes, creeping stems, and the like, which give forth branches, and constantly die away from behind forwards, and in this way the lateral shoots become independent plants. The branches, and even the leaves of many plants when separated from their plants, will, under favourable conditions, take root, and form new and independent plants. Many

plants consisting of one cell only multiply by division. It is usual to group these various modes of propagation under the head of Vegetative Reproduction.

With the exception of a few of the lower algæ and fungi, all plants in addition to vegetative reproduction exhibit true reproduction; by this is meant reproduction by means of special cells. These special cells may be produced in two ways:—

(1) *Asexually*, that is, a reproductive cell is formed, and this cell can of itself give rise to a new individual.

In the Thallophyta (from Greek *thallos* growing shoot, and *phuton* or *phyton* leaf—the Greek *u* is usually in English represented by *y*) these cells are named teleutospores (Greek *teleutē* end, and *spora* seed), uredospores (Lat. *uredo* blight), *sporidia* (Greek *spora* seed, and *eidos* form), stylospores (Greek *stylos* pillar), tetraspores (Greek *tetra* four), zoospores (Greek *zoon* an animal), conidia (Greek *konos* cone, and *eidos* form), or without any special prefix they are simply named spores.

In Muscineæ (from Lat. *muscus* moss) and vascular (from Lat. *vasculum* little vessel) cryptogams (Greek *kryptos* hidden, and *gamos* marriage) they are termed spores.

In *Rhizocarpeæ* (from Greek *rhiza* root, *karpos* fruit) and selaginella (from Lat. *selago*, kind of club-moss) there are two kinds, microspores (Greek *mikros* small) and macrospores (Greek *makros* large). Hence these plants are termed heterosporous (from Greek *heteros* other).

In Phanerogams (Greek *phaneros* manifest, and *gamos* marriage) pollen (Lat. *pollen* or *pollis*, genitive, *pollinis* fine flour) grains are the equivalents of microspores. Macrospores are represented by certain structures contained in the ovules (diminutive from Lat. *ovum* egg). Some of the spores in fungi are multicellular, that is, are composed of many cells.

In most Cryptogams coalescence takes place between two spores, which differ in size and shape, one *male*, the other *female*. These spores are developed in special organs.

The male organ is named an *antheridium*, plural *antheridia* (from Greek *antheros* blooming, from *anthos* flower, and *eidos* form), the female organ is named an archegonium (Greek *archē* beginning, *gonē* offspring) or oogonium (from *oon* egg, and *gonē* offspring). In this case the male cell is simply a minute mass of protoplasm (Greek *prōtos* first, and *plasma* formative matter) generally devoid of a cell-wall, but possesses the power of spontaneous movement, and is named the antherozoid (from Greek *anthos* flower, adjective *antheros, zoon* animal, and *eidos* form). The antherozoid coalesces with the female cell, which is named the oosphere (Greek *oon* egg, and French *sphère*, —from Greek *sphaira*, globe). After fertilisation the oosphere becomes surrounded with a cell-wall, and is then termed the oospore (*oon* egg, and *spora* seed). There is not a complete differentiation (that is, a distinct formation of the two organs) of antherozoid and oosphere in all plants. In the peronospora (Greek *peronân* to pierce) [*Peronospora infestans* (Lat. *infestare* to attack) is the cause of potato-blight], for example, the oosphere is differentiated, but the antherozoids are not; there is no differentiation in the protoplasmic contents of the male reproductive organ by means of which the oosphere is fertilised. The same holds true in regard to phanerogams, or flowering plants. In phanerogams the oosphere is fertilised by outgrowths of the pollen grains, which take place after the pollen grains adhere to the part of the carpel termed the stigma (from Greek *stigma*—from verb *stizein* to puncture—puncture of a pointed instrument). These outgrowths are termed pollen tubes; they penetrate the stigma and grow down the style, when the stigma is not sessile, till they reach the ovary and fertilise the ovules.

In the lichens (Latin *lĭchen*, Greek *leichēn*), belonging to the algæ, and in the *Florideæ* (flower-like), belonging to the algæ, the cells which correspond to the antherozoids of other Cryptogams possess a cell-wall, but are not capable

of motion, and in these plants there is no real oosphere in the female reproductive organs. Further, in other ascomycetes (Greek *askos* bag, and *mykes* or *mukos* fungus or mushroom), where sexual reproduction is known to take place there is no differentiation of either antherozoid or oosphere, but the male and female organs simply coalesce. In these plants the product of fertilisation is not a single cell but a number of cells, which are generally contained in a fructification, and for this reason are termed carpospores (Greek *karpos* fruit); while those of ascomycetes, owing to the mode of their development, are further distinguished as ascospores (*askos*, bag). Again, in certain fungi and algæ (zygosporeæ, from Greek *zygon* yoke, and *spora* seed), the two coalescing cells are generally about the same size and shape, and may either be both stationary, or endowed with movement, and in this case the coalescence is termed conjugation, and the resulting cell is named a zygospore. In this case it is not possible to say which of the conjugating cells is male and which is female.

In the Thallophytes (*thallos* young shoot, *phyton* plant) the cells which are produced sexually (oospore, zygospore, carpospore) become detached from the parent plant, and in the Phanerogams it develops to a certain extent and forms the embryo (Greek *embryon* from *en* (*em*) in, and *bryein* to swell with anything, to bud forth), but at the embryo stage its development is arrested, and it is then set free along with certain parts of the parent plant, and is known as the *seed* or *zygote.*

For a full account of the reproduction of plants some of the advanced treatises on botany such as that by Sachs may be consulted. We will now give a very brief account of the classification of plants.

## Classification of Plants.

Many systems of classification of plants have been devised for the purpose of grouping plants in accordance with recognised relationship. The principle on which

this relationship is founded may either be natural or artificial. Among the artificial systems the best known is that of Linnæus, called the sexual system, which arranges plants in accordance with the number and mode of the arrangement of the sexual organs. In Linnæus's time the sexual organs were only known to exist in the phanerogams, or seed-bearing plants. The great group of cryptogamic plants, which Linnæus considered to be a mere subsidiary group of the Vegetable Kingdom, could not be classed according to the number and arrangement of their sexual organs.

Since the time of Linnæus, the attention devoted by botanists to the cryptogams has led to a knowledge of the mode of reproduction of this most important and highly interesting division of the Vegetable Kingdom, which has revolutionised the earlier conceptions of plant-life, and has given an impetus to the philosophical study of botany impossible to overestimate. The result of the increased and increasing knowledge which has been acquired from the patient and persistent researches of skilled investigators is the establishment of the natural system of classification of plants. This system of classification is founded on the natural relationships of plants, and not on any artificial or merely external resemblances. The relationships are in fact established by Nature itself, and the classification, in accordance with these fundamental relationships, is entirely dependent upon the state of our knowledge in regard to these relationships. These depend upon the structure and other characteristics of the reproductive organs, as well as on the relation of the reproductive organs to alternation of generations. If we take the case of the higher Cryptogams, it can easily be seen that what is termed a reproductive cell, whether it has been produced asexually or sexually, does not give rise to an individual like the one that bore it. If the case of a spore is taken, it will be seen that the individual to which it gives rise does not bear spores but sexual organs; if it is an oospore, or fertilised

oosphere, it gives rise to an individual which bears spores. It will thus be seen that there are two distinct generations in the life-history of these plants: the one generation named the sporophore (Greek *spora* seed, and *phorein* from *pherein* to bear, hence spore-bearer), which is devoid of sexual organs and bears spores; the other generation is termed the oophore (from *oon* egg, and *phorein* to bear), which bears the sexual organs. These two generations are different in appearance; hence the phrase alternation of generations (Lat. *alternatio -onis* an interchange). It may be here stated that the two generations are not to be considered two independent individuals in the strict sense of the term, but rather as two distinct phases in the life-history of one individual.

For example, that very common cryptogamic plant the moss is the oophore, for it bears the sexual organs. When in the moss the oosphere is fertilised, it becomes an oospore; but the product of the development of this oospore is not an individual like the parent plant, but a fructification called the sporogonium (Greek *spora* seed, and *gonē* offspring) in which spores are formed. The spore therefore produces one generation, which bears the sexual organs, and is therefore termed the oophore; and the oospore, which results from the sexual organs, develops the sporogonium, and this is another generation, namely, the sporophore. When the spore of a fern germinates the product is not a fern plant possessing a stem and leaves bearing spores, but a flat, small body composed of cells. This body is termed the prothallus, or more usually the prothallium (Greek *prothallos* the preceding or antecedent young shoot), and produces the antheridia and archegonia; and the ordinary fern is produced from the fertilised oospheres which are contained in the archegonia. Here is a very distinct case of alternation of generations.

When the spore germinates it gives rise to the prothallium bearing the sexual organs, namely, the antheridia and archegonia; this being the one generation. When

the oospheres are fertilised by the antherozoids they become oospores. The oospores give rise to the fern which bears spores. In ascending from the fern to seed-bearing plants the alternation of generations is much more difficult to trace, owing to the smaller development of the prothallium. In the vascular cryptogams which possess macrospores and microspores, the prothallium, which is developed from the macrospore, does not become detached from the spore from which it is developed. Both the microspores and macrospores produce prothallia, those of the former only producing male organs, and those of the latter female organs; the structures which represent the female prothallia of the heterosporous plants (plants containing microspores and macrospores) are enclosed in parts which belong to the spore-bearing plant. Here it is more difficult to see clearly the alternation of generations; still, the sporophore results from the fertilised oosphere, and there is a distinct alternation of generations; though the one is not detached from the other. In Phanerogams (seed-bearing plants) the male prothallium is represented by the pollen tube. This is an outgrowth from the pollen grain, which penetrates the stigma, and is the means by which the ovules are fertilised. The structures which represent the female prothallium in the heterosporous vascular Cryptogams are enclosed in parts belonging to the sporophore. It must be remembered that in phanerogams the plant itself is the sporophore; the oophore or generation bearing the sexual organs being only represented by the pollen tube, and by certain cells of the ovule. These cells when fertilisation takes place produce the plant, which remains in the seed as the embryo until the seed germinates. Hence the pollen tube and certain cells contained in the ovule represent one generation, while the seed-bearing plant itself, or sporophore, represents another.

In the Thallophytes it is not possible to trace any approach to alternation of generations. In such a thallophyte as fucus (Lat. *fucus*, Greek *phykos* sea-weed or rock-

lichen) the only reproductive cells formed are oospores, whilst in others the same individual produces spores sexually as well as asexually at different times, and the same process may go on simultaneously. For this reason it is quite impossible to distinguish sporophore and oophore, as is the case both in the higher Cryptogams and Phanerogams. It will be seen from what has been stated that until a more perfect knowledge of the life-history of plants is acquired, any classification that can be given must only be looked upon as provisional and subject to modification with increasing knowledge. The difficulties of the subject only add zest to the skill and patience of scientific botanists who have done already so much to arrive at a knowledge of the natural affinities of plants. No classification is of the slightest scientific value unless founded on the relationships established by Nature; and it is only the difficulty of ascertaining these natural relationships that stands in the way of a complete and satisfactory classification which will keep pace with the course of evolution.

An entire treatise would be needed to give the barest outline of the classification of plants, and therefore the main divisions can only be here cursorily enumerated. The main divisions of the Vegetable Kingdom may be provisionally exhibited as follows:—

### Group I. Thallophyta.

This group consists of plants of very simple structure without any distinction of leaf and stem, having no true roots or fibro-vascular bundles.

Class 1. Algæ.
Class 2. Fungi.

Belonging to these two classes are several subdivisions. The protophyta (Greek *prōtos* first, *phyton* plant). In this group there is no sexual reproduction. The *Phycochromaceæ* (from Greek *phykos* sea-weed, and *chroma* colour) belong to the algæ, and belong to this group. To this

group also belong the exceedingly important Schizomycetes (from Greek *schizein* to divide, and *mykes* fungus).

The Zygosporeæ (from Greek *zygon* yoke, and *spora* seed or spore) belong to this group.

SEXUAL REPRODUCTION BY CONJUGATION.

Another division of the Thallophyta is the Oosporcæ (Greek *oon* egg).

Here the sexual reproduction is by fertilisation.

Another division is termed Carposporcæ, and includes the Florideæ among the Algæ and the Ascomycetes (Greek *askos* bag, and *mykes*, fungus).

### GROUP II.—Muscineæ (The Moss Group).

The plants belonging to this group are developed from spores, and usually possess a distinct stem and leaves, but are devoid of roots and fibro-vascular bundles. These plants also bear the sexual organs, and the fertilised oosphere gives rise to a capsule which contains the spores. The ordinary plant is the oophore, and the capsule the sporophore.

Class 3.—Hepaticæ or Liverworts (Greek *hēpar hepatos* liver).

Class 4.—Musci (Latin for mosses).

### GROUP III.—Pteridophyta (Greek *pteris pteridos* fern, and *phyton* plant).

A small prothallium is developed from the spore, and this bears the sexual organs (oophore).

The plant developed from the fertilised oosphere possesses a stem, leaves, and roots, and is further distinguished by its characteristic fibro-vascular bundles.

Class 5.—Filices (Latin *filices* ferns).

Class 6.—Equisetaceæ (Lat. *equisētum* [*equus* a horse] the plant horsetail, hence the 'horsetails').

Class 7.—Lycopodiaceæ (Greek *lykos* wolf, *pous podos* foot).

GROUP IV.—Phanerogamia (Seed-bearing Plants).

The plants of this group produce true seeds, which, when mature, contain a minute plant, the embryo (Greek *bryein* to swell with) possessing a rudimentary root, stem, and leaves. The ovule contains the oosphere, and from this the embryo is developed after fertilisation.

Belonging to the Phanerogamia we have first the Gymnospermæ (Greek *gymnos* naked, *sperma* seed).

Class 8.—Gymnospermæ.

Another division of the Phanerogamia is the Angiospermæ (Greek *angeion* vessel, and *sperma* seed).

Class 9.—Monocotyledons (Greek *monos* one, and *kotylēdōn* seed-leaf).

Class 10.—Dicotyledons (Greek *dis* twice, and *kotylēdōn*, having two seed-leaves).

In the Gymnospermæ the ovule is not enclosed in an ovary (modern Latin *ovarium* from *ovum* egg), but is either attached to the open carpel, or, if no carpel is present, to the axis.

In Dicotyledons the earliest seed-leaves are opposite to one another, while in Monocotyledons the earliest seed-leaves are alternate.

The leaves of monocotyledons have usually parallel veins.

There are many other characteristics which are peculiar to these divisions of flowering plants, and, as might be expected, they gradually shade into each other in certain plants.

The plants of each great group are further divided into smaller groups, termed natural orders; each natural order being made up of groups termed genera, and each genus is composed of plants resembling one another in many points, and termed species.

Species may be further divided into varieties. A full account of the classification of plants would occupy a large

amount of space. For this and many other particulars, here merely referred to, special treatises on classification may be consulted.

### VEGETABLE KINGDOM.

*The Effect of Climate on the Character of the Vegetation.*

Dr. Hans Meyer has described—in his *Journey across East African Glaciers* (an account of the *First Ascent of Kilima-njaro*)—the character of the vegetation of the regions through which he passed.[1]

Leaving the Rabai Mission, Dr. Meyer enters the plateau on whose edge it stands.

'The heavy showers of the past few days which heralded the approach of the rainy season, had been general all over the region, and had already filled the rock-reservoirs on which we had to depend for our supply of water. Under their fostering influence the vegetation had begun to awake from its long sleep, and already showed signs of returning life and vigour.

'The whole of the plateau country has the appearance of an arid, wooded wilderness, in which evergreens mingle with deciduous coarse grasses, and low bushes cover the clayey soil.

'The trees are tolerably close to each other in the neighbourhood of the coast, though they do not attain any considerable height, as they do among the mountains, or along the banks of water-courses. The trunks are short, the bark cracked, the branches gnarled, and in many instances withered.

'Islands and belts of impenetrable thickets of succulent shrubs are interspersed in all directions amongst the trees.

'The farther the traveller penetrates into the interior and leaves the moist zone in the neighbourhood of the

[1] For permission to insert the following extracts from Dr. Meyer's valuable work, we are indeb ed to the courtesy of Messrs. George Philip & Son, who have recently published an English translation of this very vivid record of the exploration of German East Africa.

sea, the more he finds that the vegetation is protected against excessive evaporation.

'In the vicinity of Taro, only three days' march from the sea, the evergreen forms begin to disappear, and growths of thorn predominate.

'Towards the Maungu mountains the open woods give place to a dense "hawthorn scrub" containing only three species; and on the farther side of the small dividing wall of the Maungu mountains, the tree-steppe is uninterruptedly contiguous with the arid forest. At first, the tree-steppe is studded with isolated clumps of thorn bushes intermingled with forest growths, but farther on, beyond the mountains of Taita, it appears in all its dreary openness.

'The tract of country here shortly described, between the coast and Kilima-njaro, is botanically divided into four regions corresponding to climatic and geological conditions, and to the prevailing abundance or scarcity of water.

'During the dry season, rain-water is still found in rock cavities, and in pools as far as Taro; between Taro and Maungu, water is entirely wanting; the same is the case between Maungu and Ndara-Taita, as well as between Taita and Taveta; whilst on the western Ndara slope rain-water is still found as well as two brooklets.

'When it rains, water collects in small pools close to Maungu, and between Taita and Taveta.

'It is natural that, in regions such as that of East Central Africa, where the plains are of vast extent, and where hills seldom meet the view, the physiognomy of the region should be determined almost exclusively by the vegetation. But the character of the vegetation itself depends everywhere more on the form and arrangement of the parts of the plants which serve for their protection and nourishment, and on the structure of the leaves and wood, than on the form of the reproductive organs and the flowers and fruits. This was indeed very strikingly shown at the beginning of the period of vegetation.

'Whether flowers were absent at one place, and were blossoming with dazzling splendour and in countless numbers at another, and whether they were large or small, white or coloured, their presence only affected the characteristic aspect of the landscape in a small degree.

'The leafless trunks and boughs on the other hand form the ground sketch of the picture.

'They plainly bear the stamp of climatic extremes, and are equally affected by the nature of the soil due to these extremes of climate, for which reason the many species composing the forest are fashioned so like each other as to give the impression that only a few species are represented, as in the oak and beech forests of more temperate regions.

'Whilst, indeed, the stems and branches form the skeleton of the flora, this flora first acquires body by means of the leaves, and here in this desert region the leaves are either all bipinnate, so that the smallest possible surface is exposed to evaporation, or they develop a tough, glossy cuticle, to protect them from injury through excessive transpiration.

'The woods are for the most part composed of tall evergreens,—mimosæ, tamarinds, and olives,—and of deciduous trees such as banyans, sycamores, and willows. Dwarf palms and low oshur and sodada shrubs, epiphytic orchids, cane and prairie grasses, with many tuberous and bulbous species, find their place nearer the ground.

'When trees are absent, these more inconspicuous members of the Vegetable Kingdom become inextricably mingled with Euphorbias, Cucurbitaceæ, bulbous-stemmed testudinaria, and aloes, and form impenetrable thickets.

'The primary object of Nature in the organisation of each and all of these plants has been protection against evaporation, for the drought to which they are subjected lasts for months at a time.

'In the attainment of this object, Nature displays a wonderful fertility of resource.

'It has been already stated that certain species, like the

Mimosæ, the banyans, and the sycamores, are furnished with pinnate, or thick glossy leaves, which drop off at the beginning of the dry season, after having fulfilled their nutritive function; in others the leaves are evergreen, but abnormally tough, and the greater number are covered with an armour of thorns over stem, branch, and twig alike. In some cases the leaves are entirely represented by thorns. The succulent plants are, as it were, clothed in mail, which prevents the evaporation of the sap; and in plants belonging to the grass and onion orders a store of moisture is laid up in the underground tubers and bulbs.

'When I passed through this region two years ago, in the month of July—that is to say, in the height of the dry season—the landscape was painted in a dull grey monotone.

'On the present journey the colouring was little less dull; for the young leaves had a grey or bluish sheen, and decayed grasses, branches, and trunks of trees were visible everywhere, except in places where they had been destroyed by fire or white ants. The breath of spring had nevertheless passed over the land. Many of the plants were pushing out their young leaves, while others, and those the majority, like the alders, hazels, willows, and fruit-trees of temperate climates, were crowned with a mass of blossom, while as yet their foliage leaves were still in bud.

'This phenomenon is quite explicable as far as the trees of temperate climates are concerned, where the rays of the spring sun affect the more delicate outer envelopes of the flowers more quickly than those of the leaves; but it is difficult to account for this in equatorial climates, where the stimulus due to light and heat remains nearly the same throughout the year.

'The explanation would seem to be connected in some way with the necessity which exists, that fertilisation should take place before the pollen is spoiled by the heavy rains.

'The various lilies and orchids follow the example of the

plants above described; but the grasses produce the leaves first, and succulent species new shoots.

'In these last the tubers have afforded a continuous supply of moisture throughout the whole of the dry season, and the plants are thus in a condition which enables them to utilise at once for the purpose of growth the surplus nourishment supplied by the rain.

* * * * * *

'During the last hour we have quickly emerged from the region of arid forest, which up to this has prevailed, and are now wandering in the midst of the wilderness of hawthorn scrub.

'The appearance of the landscape for miles round is exactly that of a plantation of fruit-trees regularly arranged in an open arable field.

'In direct relation to the conditions necessary for the acquirement of nourishment from the air and soil, these trees vary in height from six to twelve or thirteen feet, and are pyramidal in shape.

'The trees are distributed at regular distances of from nine to twelve feet over the plains, and have a striking resemblance to wild pear-trees in winter, in so far as their branching begins a short distance above the ground, in their light-grey trunks festooned with trailing lichens, in the rigid character of their branches, and in the great development of thorns. It is only at certain places that the dull monotonous red is relieved by a few tufts of grass, shrubs and bushes being absent. A slender twining plant, with a saccate tuberous stem from sixteen inches to three feet long, is the one constant associate of the thorn-trees throughout the whole area. The great majority of the trees had just expanded their leaf-buds, and at the same time on a few of them small white or yellow flowers had appeared.

'In spite of their remarkable similarity in external appearance, and in other distinctive features, it could be seen on closer inspection that there were three different species

present. Of these, thorn shrubs, one with trilobate leaves, and another with finely pinnate leaves, were found in the dry forest as far as Taro; but in this district they are the preponderating companion plants; whilst the third species, which was still leafless, was new.

'The most marked effect of the extremes of climate on this vegetation is the enormous development of thorns throughout. The excessive abundance of thorns is less for a defence against animals—for the great plant-eaters, loving the open landscape of the steppe, would perhaps not feel at home in this confined wilderness—than as a means of protection against the drought of the dry season, which in this region appears to be especially severe.

'Griesebach in his classical work, *Vegetation der Erde,* brings into prominence the fact that Nature everywhere in the domain of the organic world fulfils the most varied ends of life by the same means, and always in accordance with external requirements, by developing organs according to the one or other purpose, from within outwards, through the most minute modifications.

'In the case under consideration, the protection afforded by Nature is two-fold, viz., against animals and drought; and this is effected by the partial suppression of the leaves, and instead of a leaf the tissues of the vascular bundles from the axis of the twig are hardened to woody thorns of from five to six centimetres (from two to two and two-fifth inches) in length, these at a later period again grow to twigs and develop thorns.

'The thorns surround the branch alternately with the leaves in the sense of a spiral; and the end of a branch instead of terminating in a leaf terminates in a pointed thorn.

'It is evident that the transpiration of the plant is retarded by such a diminution of the number of the leaves, and that the thorn-tree can the longer retain its sap when, after the end of the rainy season, the roots can no longer absorb moisture from the soil.

'The thorns spring from the twigs, the twigs from the branches, and the branches from the trunk almost at right angles.

'It is a picture of plant life of a wonderfully angular aspect and defiant character.'

## Parasitic Plants.

Some allusion should here be made to an interesting class of plants termed Parasites (Greek *para-sitos—sitein* to feed—eating beside). Among flowering plants, parasites belong exclusively to the two divisions Gamopetalæ (Greek *gamos* marriage, and *petallon* leaf), or those plants whose petals are coherent, and Monochlamideæ (Greek *monos* single, and *chlamys chlamydos* mantle), or plants with a single floral envelope. Parasitic plants are nourished wholly or partially at the expense of other living plants, which in relation to the parasites are named their 'hosts.' The extent of the benefit thus received varies very greatly with different plants. The effect which the parasite produces on the host may be, so far as external changes show, quite imperceptible, or in other cases the host may fall a victim to the ravages of the parasite. This, of course, depends on the nature of the attacking plant; for there are certain plants which get all their nourishment from the host, while both host and parasite continue to live together in intimate association, perhaps to the benefit of both. This is, however, by no means the only condition; for parasites are often the most deadly enemies both of animals and plants. Between the mutually harmless, and probably beneficial association of the two plants, there is a gradual gradation, by which the effect on the host becomes more and more apparent, until the extreme limit when the parasite saps the vitality of the host, and decay and death are finally brought about.

This has special reference to the baleful effect of parasitic fungi both on man and animals.

The parasitic fungi are in near alliance with another

group termed Saprophytes (Greek *sapros* putrid, and *phyton* plant); though Saprophytes are not true parasites, or rather are not to be classed with the Parasites at all. The Saphrophytes do not obtain their nourishment from living organisms, but feed on the dead remains of organisms.

All true parasites are confined to the dicotyledonous flowering plants on the one hand, and to fungi on the other. Beyond the fungi, a few partial parasites belong to the Algæ, which are more or less nearly allied to the fungi.

Frequent reference is made to parasitic plants by early writers, though the vagueness of the references is such as to leave it doubtful whether they regarded the parasites as independent plants, that is as distinct individuals, or merely as excrescences produced by some abnormal conditions of growth. It is true that Pliny knew that the mistletoe was a parasite having a distinct individuality apart from its host; for he gives an account of its reproduction by seed.

Doubtless the effects of parasitic fungi were very early observed; for, considering the damage they are capable of inflicting, it would be impossible to suppose that no special attention had been devoted by these early and acute observers to the prime cause of the diseases that so often attack growing crops and plants of various kinds. That so little was known about the most interesting and most deadly class, the parasitic fungi, is due to their extreme minuteness. The enormous improvements made in the manufacture of microscopic lenses, and the high powers of object-glasses that can now be used, together with the immensely improved methods of research, have enabled bacteriologists to gain an insight into the life-history of these fungi never dreamt of by the ancients. No branch of science has perhaps more enthusiastic followers than bacteriology; and in consequence the classification of these lowly organisms is continually liable to alteration and modification, as new facts are brought to light. Even in regard to the parasitic flowering plants, it was not till

the middle of the eighteenth century that any attempt at classification was made. At that time Pfeiffer published a treatise on a certain fungus, and made an attempt at classifying both the flowering and more obvious cryptogams, which he considered to be parasitic. He divided the parasites into groups; the flowering parasites were grouped in three divisions according as they attacked the entire plant, or were found only in one part of the plant, or were confined entirely to the root. Pfeiffer includes among his parasitic plants many Epiphytes (Greek *epi* on, *phyton* leaf), that is, plants which though growing on others derive none of their nourishment therefrom, but are entirely dependent for their nutrition on the store of material supplied by the atmosphere, and that taken in liquid form from the soil. Flowering plants such as ivy, and flowerless plants such as lichens, were classed by Pfeiffer among true parasites, but this classification is quite erroneous.

After Pfeiffer's time a more extended knowledge of Nature and exotic (Greek *exotikos—exo* outside) forms continued to be acquired, but no striking advance was made nor any very decided views entertained on the subject until the end of the last century and the beginning of the present, when observers adopted the old notion that parasites were merely degenerate outgrowths from their hosts; that is, a species of abnormal excrescences. It was even asserted that at least several well-known parasites were only degenerated species of certain plants to which the parasites had a fancied resemblance, as, for example, the large parasite *Rafflesia*, was considered to be a degenerate cabbage.

De Candolle, the celebrated French botanist who did so much to advance the classification of Phanerogams on the basis of the natural system, made the first attempt to classify parasites on a morphological (or in accordance with their structure) and physiological basis. De Candolle's classification was published in the year 1832.

Further reference will be made to the interesting subject of parasitic Fungi in the article giving some account of

Bacteria. The fact that in such a progressive science as bacteriology the classification of to-day may be, so to speak, obsolete to-morrow, will only add zest to the labours of the enthusiastic student, eager, perhaps, to assist in contributing his share to the fuller knowledgē which is destined to benefit the human race, and lead to the lessening of the evil and deadly effects of those parasites whose action is so often productive of fatal results.

## Movements of Plants.

Scarcely any one can have failed to notice that many plants close their flowers when evening approaches, others again at various periods of the day, whilst some close their flowers when the sky is overcast; foliage leaves also are in many casses subject to periodic movements.

The movements of different plants are dependent on various causes.

Some of these movements are solely mechanical, and caused by the tissues being affected, owing to the condition of the surrounding air and to varying states of turgidity and exhaustion.

Other movements are apparently due to physical causes, but cannot be fully explained by attributing them to these causes.

Movements in plants also depend upon the contractile quality of the protoplasm in the cells, and on the passage of the protoplasm from cell to cell. The property of the protoplasm gives rise to movements caused by the plant itself, which are not at least directly due to any external exciting cause. These movements can be compared with the movements of the lower animals, and to the ciliary motion found in certain tissues belonging to the most highly organised animals.

The periodic movements, such as the 'waking' and 'sleeping' condition of leaves, the closing of flowers, etc., are manifested only when the organs are fully matured, and when the peculiarity of their internal

structure which gives rise to the phenomena of periodic movements is fully developed.

These movements are to be carefully distinguished from those due to unequal growth, such as movements of nutation. In this case there is no special structure upon which the movements depend.

The bursting of seed-vessels, anthers, etc., is due partly to the fact that the condition of the tissues, as regards the amount of liquid they contain from their possessing unequal power of imbibing moisture, is not equally elastic. For this reason, when the less elastic portions of tissue are subjected to strain they are torn apart or bent in various ways, owing to unequal contractions and expansions, caused by an access or withdrawal of moisture.

These cases can scarcely be regarded as vital phenomena, but should rather come under the category of what is in ordinary language named 'warping.' They are simply caused by particular modes of the destruction of dead tissue due to conditions brought about by variations in the structure of the tissues in questions.

Movements in plants which take place periodically, such as sleeping and waking, or those movements that take place when they are touched or otherwise affected by certain kinds of exciting stimulus, cannot be attributed to mechanical causes. The slightest mechanical stimulus on the sensitive plant, *Mimosa pudica*, causes the leaflets to fold together. Such movements are not proportional to the external stimulus, but depend on the internal structure of the plant.

To this class of movements have been added the very remarkable movements which give rise to the twining condition of certain stems.

Another class of movements may be mentioned, viz., movements of the protoplasm in cells, or movements of free bodies, such as zoospores (Greek *zoon* animal, and *spora* seed), antherozoids (Greek *anthos* flower, *zoon* animal,

*eidos* form), and sometimes even perfect individuals, such as Desmediæ, etc., which may have the power of temporary or permanent locomotion.

Mr. Francis Darwin discovered that fine threads of protoplasm are protruded from the pear-shaped glands of the common teasel (*Dipsacus*). These threads are capable of contracting. In this case the cell contents move, just as in the case of the cell contents of other plants, or certain entire plants.

The rotation of the protoplasm of cells is attributed to causes similar to those which produce locomotion in the simpler plants, and these movements are strikingly like some of the movements of the Protozoa in the animal kingdom. The movements of the products of cell contents having no cell-wall, such as zoospores and antherozoids, is generally caused by the rapid movement of cilia (plural of the Latin word *cilium* an eyelid) or small filaments which cover the surface. The locomotion of certain plants, such as Diatomaceæ, is apparently not due to cilia.

Sensitive plants, such as the *Mimosa pudica*, are strongly affected by any mechanical stimulus, and thus afford us examples of the phenomenon named 'irritability.'

The sleep of plants is most probably a case of irritability, and differs only in degree, not in kind.

Sensitiveness in plants is affected both by light and heat. It has been experimentally proved that sensitive plants, if kept in the dark, lose their sensibility after a period of seven days, and actually die after twelve days.

We know that white light is composed of light of different colours. Light is propagated in waves, and each colour is distinguished by having a different wave-length from that of any other colour. Red light, differs, for example, from violet light in the length of its waves, and violet light differs from blue, etc.

It is therefore not surprising to find that the different-coloured rays are capable of producing different effects.

It has been ascertained that under the influence of green light sensitive plants die after sixteen days' exposure, though they retain their sensibility for twelve days.

When the plants were exposed to violet and blue light, their growth completely ceased. They, however, retained their vitality as well as their sensibility for three months. The effect of heat on sensitive plants has also been ascertained.

The sensitiveness and periodical movements of *Mimosa* do not begin till the temperature of the surrounding air exceeds 15° C. The periodical movements of the lateral leaflets of the Indian telegraph plant (*Desmodium gyrans*) can only occur when the temperature exceeds 22° C.

When the temperature of the air is 40° C., the leaves become stiff in less than an hour, and at 48° C. to 50° C. rigidity takes place within a few minutes; but when the temperature falls, the sensitiveness may again be manifested.

A temperature of 52° C. not only causes loss of permanent motion, but also the death of the plant.

The mechanism to which the periodic movements of plants is due is not by any means fully known.

In *Mimosa pudica* there is a pulvinus or swelling at the base of the petiole.

The cells composing this swelling may be compared to two springs acting in a contrary sense. If any influence causes one of these so-called springs to become incapable of acting, the other spring causes the leaf to move in the direction of least resistance. These springs, as they may be called, are in a state of equilibrium so long as the cells composing them are equally distended by moisture. When, however, a rapid ingress of liquid takes place in such a manner as to produce a turgid condition in the one set of cells while the other set remains comparatively empty, the condition of equilibrium no longer exists and movement ensues.

The particular circumstances which regulate the turgidity have not been, so far, determined with precision.

It has, however, been clearly ascertained that this turgid state is associated with the passage of fine threads or filaments of protoplasm from one cell to another, and at the same time with an accumulation of a soluble chemical compound named glucose, a kind of sugar, in fact. This substance possesses great osmotic power, that is, it can pass very rapidly through the flexible cell-walls of the pulvinus forming the so-called springs. These movements are therefore closely connected with the rapid absorption and expulsion of liquid.

The motions which take place independent of external stimuli, as well as those due to an external exciting cause, are not always of the same character. Bert and Mîllardet state that the movement which takes place spontaneously in the *Mimosæ* is not limited by a simple depression, to be followed after some time by elevation, such as occurs in the case of most plants whose leaves sleep. The movements of depression and elevation according to Messrs. Bert and Mîllardet are continuous, the one alternating with the other. It would thus appear that the leaves of the *Mimosæ* do not remain for a certain period in a motionless condition, as is the case in most plants whose leaves, under ordinary conditions, have their periods of movements and rest.

Contrary to the habit of most plants, the sensitive plant raises its leaves at night and closes them by day.

The most usual kind of movement in these plants is that in which the leaves as well as the floral envelopes assume the position they occupied before the buds opened.

Compound leaves, such as the leaves of the *Leguminosæ*, or pea-family, exhibit a simple or compound movement.

The leaves of the bean fold upwards, those of the *Lupinus* fold downwards. In Tamarinds the leaves fold to the side. In some other plants the common petiole of the compound leaves becomes raised or depressed, while the leaflets turn downwards or sidewise. This is the case in *Amorpha fruticosa* and *Gleditschia tracanthus*.

In the well-known *Mimosa pudica*, which is a hot-house

plant in temperate regions, the leaflets fold together, the small stalks of the leaflets of the compound leaves of this plant approach each other, and the main petiole becomes depressed.

In one exceedingly sensitive species of *Oxalis,* the pinnate leaves fold upwards. A footfall is said to be sufficient to cause it to close its leaves.

When these movements of leaves or leaf-organs take place at stated hours, and when the leaves remain in the new position after the movement has ceased until a particular period of time recur, the closing up is called the *sleep* of plants. This condition is observed both in seed-leaves and true leaves, as well as in the petals of flowers.

So far as can be made out, the object of this closing of the leaves seems to be to prevent the chilling effect due to radiation from being injurious to the plant. This folding up causes a smaller extent of surface to be exposed. Radiation of heat during a clear night, goes on rapidly from all surfaces such as those of expanded leaves. The closing of the leaves may be supposed to form a protective covering, which prevents the heat passing away into space, and thus saves the plant from the injurious effects of cold.

This is only true of the foliage leaves, which expand during the day and close during the night.

The period at which the movement of closing and opening of flowers takes place is very varied. Ordinary leaves, as has been stated, close towards evening and open in the day. The periods of opening and closing in the case of flowers vary considerably, being affected no doubt by the visits of insects, which carry the pollen from plant to plant belonging to the same species. By this means flowers are fertilised, and the seeds resulting from plants that are so fertilised are much more numerous than those resulting from self-fertilised plants. Some plants, such as the pimpernel, close their petals when the sky is overcast. This is doubtless to protect the pollen from the injurious

effects of rain. This kind of closing, however, is not to be confounded with the regular and periodic closing and opening of flowers.

The diversity in the regular and periodic opening and closing of flowers in regard to time is so great that Linnæus was able to arrange flowers in a list in accordance with their times of opening and closing.

This list he named a *Horologium floræ,* or floral clock, the time of opening or closing representing each succeed ing hour.

Some closing flowers open under the influence of strong artificial light, such, for example, as *Crocus* and *Gentiana verna*; on others, however, such as *Convolvulus,* artificial light has no effect.

The closing of flowers is usually a slow process, as may easily be observed, but there are exceptions to this.

'In *Desmodium gyrans*' (the Indian telegraph-plant) 'the trilobate compound leaf has a large terminal leaflet and a smaller one on each side. When the plant is exposed to bright sunlight in a hot-house, the end leaflet stands horizontally, and it folds downwards in the evening, but the lateral leaflets move constantly during the heat of the day, advancing, edgewise, first towards the end leaflet, and then returning and moving towards the base of the common petiole alternately on each side, in a manner very well compared to the movements of the arm of the old semaphore telegraphs.'

Such are some of the more striking movements of plants. Even in cases where the precise advantage, as far as regards the economy of plant life, is not fully ascertained, it cannot be doubted that such movements are advantageous. In strict accordance with the accepted theory of Evolution, no peculiarity would be continued from generation to generation of either plants or animals, if it possessed no essential characteristic which helped the plant or animal to hold its own in 'the struggle for existence.'

FLORA OF INDIA.

Mango groves scent the air with their blossoms in spring and yield their abundant fruit in summer. The spreading Banyan with its colonnades of hanging roots; the stately Peepul, with its green masses of foliage; the leafless cotton-tree, glowing with heavy crimson flowers; the tall feathery Tamarind and the quick-growing Bâbul rear their heads above the fields. As the rivers approach the coast, the palms begin to take possession of the scene.

The ordinary landscape in the delta is a flat stretch of rice-fields, fringed round with evergreen masses of bamboos, cocoa-nuts, date-trees, areca, and other coroneted palms.

This densely peopled tract seems at first sight bare of villages; for each hamlet is hidden away amidst its own grove of plaintains and wealth-giving trees. The bamboo and cocoa-nut play a conspicuous part in the industrial life f the people, and the number of products derived from them, including rope, oil, food, and timber has been dwelt on by many writers.[1]

The really tropical flora of the hotter and warmer parts of Eastern India is continuous with the flora of the Malayan Peninsula and the Malayan Islands, and stretches along the lower ranges of the Himalaya, gradually becoming less marked, and rising to higher elevation as we go westward, where the rainfall diminishes and the winter cold increases.

The vegetation of the higher and therefore cooler and less rainy ranges of the Himalaya has a very uniform character along the whole chain, and a closer general approach to European forms is maintained. An increase of the number of species identical with those of Europe is found.

The vegetation of the hot and dry region of the south-west of the continent consists largely of plants which are diffused over Africa, Baluchistan, and Sind; many of these extend into the hotter parts of India, and a con-

[1] For this and many of the following facts we are indebted to the *Encyclopædia Britannica*.

siderable number of Egyptian plants are to be found in the Indian peninsula.

The whole number of species of plants in the regions of South-eastern Asia, which includes India and the Malayan peninsula and islands, from about the 65th to the 105th meridian, is estimated by Sir J. D. Hooker at from 12,000 to 15,000.

The principal orders, according to their numerical importance, are as follows:—*Leguminosæ, Rubiaceæ, Orchideæ, Compositæ, Gramineæ, Euphorbiaceæ, Acanthaceæ, Cyperaceæ,* and *Labiatæ.*

Within this region, however, there is a very great difference between the vegetation of the more humid and more arid regions, whilst the characteristics of the flora of the higher mountains differ wholly from those of the plains. In fact there is a somewhat heterogeneous assemblage of tropical, temperate, and Alpine plants. In the perennial humid regions of the Malayan peninsula and western portion of the archipelago, the plains are everywhere covered with dense forests rendered difficult to traverse owing to the thorny cane.

A very comprehensive account of the flora of India will be found in Hooker's *Flora Indica.* For those who wish systematic instruction in this subject, Oliver's *Lessons in Indian Botany* should be read. For a full account of the vegetation of the earth, Griesebach's classical *Vegetation der Erde* will supply ample information for those who have time to devote to this most interesting subject.

### The Forests of India.

It is proved beyond the possibility of doubt that a moderate extent of forest has a most beneficial effect, both on the agricultural and manufacturing interests of a country, as well as on its productive resources at large.

The beneficial influence of forests in a physical, economical, and hygienic aspect is now attracting more of the

attention which its importance deserves. The countries bordering the Mediterranean—Spain, France, Italy, and Turkey—have all suffered most severely from the indiscriminate and wholesale destruction of the woods which covered the mountain slopes; and many springs which formerly existed under the shelter of the forests have now completely disappeared.

The insular position of the British Isles and the moist climate save them from suffering from the want of forest in a degree equal to that of continental nations; and it may be owing to this that the Anglo-Saxon race has been slow to recognise the value of the forests with which nature has so liberally clothed the earth. The history of America, Australia, South Africa, and New Zealand bears testimony to the same imprudence and want of consideration. One of the causes of the terrible famines in India and China is undoubtedly the reckless denudation of mountain slopes, where the forests formerly absorbed a large portion of the rainfall which now quickly runs off to the sea. No point has been more clearly established than the health-giving and fertilising effect of forests on the climate of India.

It is beyond doubt that vast tracts of woodland have a most powerful effect on the economy of the globe.

The direct effects may be summarised from results arrived at by Humboldt and others:—

(1) The screening of the soil from the heat of the sun's rays.

(2) The cooling process of radiation induced by the immense surface these leaves cover.

(3) The copious evaporation of moisture from the leaves.

Some of the indirect benefits which occur from the presence of forests may be mentioned, such as the maintenance of equable temperature and humidity, the affording of protection and shelter, the control of the regular flow of rivers, and the supply of perennial springs which fertilise and beautify the country. When the ground is covered with vegetation, the whole of the sun's heat falls

on the vegetable covering, and as none of it passes directly on to the soil its temperature does not rise so high as that of land with no vegetable covering. The temperature of plants exposed to the sun does not rise so high as that of land with no vegetable covering.

It is a well-known fact that heat is convertible into work, and work into heat. Now work is expended in converting water and other liquids into vapour. The amount of water evaporated represents the disappearance of a definite quantity of heat. When water begins to boil its temperature does not continue to rise. The heat supplied is all spent in doing work; viz., in evaporating the water. It is for this reason that the temperature of plants does not rise so high as that of soil. A portion of the sun's heat is lost, as heat, in evaporation, and the heat cannot accumulate on the surface of leaves as it does on the soil. Hence the essential difference between the climates of two countries, the one well covered with vegetation and the other not, lies in this, that the heat of the day is more equally distributed over twenty-four hours in the former case, and is therefore less intense during the warmest part of the day. But the effect of vegetation on the distribution of temperature during the day is most markedly shown in the case of forests. Trees, like other bodies, are heated and cooled by radiation: by radiation is meant that a hot body at a distance sends out waves which are absorbed by other bodies, which in this way become heated. The heat-producing rays from the sun raise the temperature of some bodies much more rapidly than others. Soil, for example, becomes more rapidly heated than water. Bodies are capable of being heated not only by radiation but by conduction and convection. Liquids may be heated either by radiation, conduction, or convection. If, for example, water is put into a vessel, and the vessel is placed over a fire or lamp, the water at the bottom of the vessel is first heated; it becomes lighter than the water above, provided all the water in the vessel is above 4° C., the

warm particles rise to the top, and in doing so part with heat to the colder particles with which they come in contact. This continues until the water has attained a uniform temperature. Here the heat is carried by the lighter portions of the water to the heavier or colder; hence the term convection. Water, however, can also be heated by conduction. If a long glass cylinder containing water be heated at the top, it is evident that there can be in this case no heating by convection unless the water in the cylinder is all below 4° C. Since at 4° C. water bulk for bulk is heavier than at any other temperature, it is clear that the surface water below this temperature when heated would sink, and this process would continue to go on until the whole water in the vessel was raised to 4° C. It is thus possible to heat water which is below 4° C. up to this temperature by convection, even when the heat is applied at the top of the vessel. The further heating of the water in this case takes place by means of the heat travelling from one particle to another, just as in the case of a rod of iron with one end in the fire. Water, however, is a very bad conductor of heat. So much is this the case that in a glass-tube two feet long, lying in a horizontal position, water can be boiled at one end while there is ice at the other.

Now trees, like other bodies, can be heated by radiation from the sun, but from the fact that trees like water are bad conductors of heat, their rate of being heated and cooled by radiation is slow. It is not until some hours after the air has attained its highest temperature that forest trees acquire their maximum temperature; and when the air has acquired its lowest or minimum temperature, it is some hours before the same is the case with trees. It is obvious from this that a large number of trees tend to prevent extreme cold and heat. The effect of radiation in the case of trees is not chiefly confined to a surface layer of air of a few feet in thickness, but extends throughout a stratum of air equalling the height of the trees.

Evaporation also proceeds slowly from the damp soil usually found beneath trees, since it is more or less screened from the sun. The air under trees is not much agitated or put in circulation by the winds, and hence the vapour ascending from the ground, instead of being carried off by the wind, accumulates amongst the trees, and in this way forests increase the humidity of climates within their influence. Besides this, when rain falls, less of it passes along the surface into streams and rivers, a very considerable portion of it being taken up by the leaves of the trees, and falling down slowly penetrates the soil, which is very friable in woods. The rain which has in this way penetrated the soil is taken up by the roots of the trees and is drawn up to the leaves, where evaporation takes place, and thus increases the humidity of the climate. Apart from the value of forests in their beneficial effect on climate, the value of the timber produced is very great, and this is especially the case in regard to India.

The earlier rulers of India, and even the British rulers in later times, took no pains to prevent the wholesale and aimless destruction of the forests of India. The magnificent trees were either cut down indiscriminately or forests were burned. This, of course, had a deteriorating effect on the climate, and led to the impoverishment of the people. Means have now been adopted to preserve the forests, and the forest department is now a branch of the public service.

A committee was appointed by the British Association in Edinburgh in 1850 to consider the 'probable effects, in an economical and physical point of view, of the destruction of tropical forests;' and in 1851 a report was presented, showing the importance of preserving every influence which tends to maintain an equilibrium of temperature and humidity, and of preventing the waste of valuable material, and pointing out the importance of the special application of the native timber trees to various uses. Indian botanists were fully aware of the value of the timber which could be obtained from the forests, and im-

pressed on the Government the necessity of adopting urgent measures to arrest the wholesale destruction of their valuable forests.

The progress of agriculture, the rapid extension of railways, and the advance of civilisation made it imperative that a general system of forest administration should be organised to control the clearing of indigenous forests, and to prevent the wanton destruction of public property.

The first attempts in this direction were made about 1858, and the local administrative bodies were intrusted with the executive arrangements. Conservators were appointed in Burmah and Madras, and these had to begin their important duties without assistance from persons skilled in forestry, but were assisted by those engaged in other services in India. After the meeting of the British Association in 1857, a staff of five or six assistants was stationed in each of these provinces, and they devoted their energies to mapping out the more valuable forests, and collecting information regarding their resources.

The Government of India in 1862 instituted a departmental system of forest-conservancy for the whole empire, and appointed an Inspector-General of Forests.

Power was given by a Forest Act in 1864 to local administrators to define the limits of State forests, and to reserve certain trees for State purposes; and this Act also defined the method of procedure in case of damages by fire and other destructive agencies. At first many of the forest officers were appointed because of their local knowledge and their love of natural history rather than their knowledge of practical forestry, but as the operations of conserving and utilising the forests were extended, the need of trained assistants was soon felt to be indispensable. It was then that a proposal to train young men specially for the work was carried into effect. In France and Germany forestry is a branch of the Government service, and five or six young men from England were sent to the forest schools at Nancy and Hanover to be

specially instructed both in theoretical and practical forestry with a view to being sent to India.

Instruction for this purpose is now given at the Royal Engineering College, Cooper's Hill.

The officers of the higher grades have been greatly increased, and now amount to about one hundred and fifty. Many large and valuable forests are in the territories of the native chiefs, and to prevent the wholesale destruction of these, the British Government takes them on lease for a long term of years. The forest lands throughout India are charged with grazing and other village rights.

Dr. Müttrech has very recently given an account of the exact climatic influences exerted by forests so far as Austria and Germany are concerned. This influence seems to be greater in the months extending from May to September or October than in the other months of the year. The daily variation of the temperature of the air in pine and fir woods rises gradually from January till it reaches a maximum in August or September, and then falls more rapidly till it reaches a minimum in December. In beech woods, however, a minimum occurs in April, then a rapid rise takes place until the maximum is reached in July. The daily variation itself is greatest in May and June, both in forest and open country. The influence of forests is to lower the maxima and raise the minima, and the former influence in most months is greater than the latter; though in December and January, and sometimes in neighbouring months, it is less. The influence on the maxima in summer is greatest in beech woods, less in pine, and least in fir. The absolute value of the influence in forests of a given kind of tree is affected by the greater or less density of the forest, being higher the more closely the trees grow together.

# THE DARWINIAN THEORY

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IT is necessary to state that a distinction must be made between Evolution and Darwinism. Evolution is the term used to denote the changes, taken as a whole, that have fashioned the universe, and the changes still in process of operation, and the final effect of these on the visible universe.

Darwin expresses the mode of the process of evolution in his famous statement: *The Origin of Species by Natural Selection*, or *the Preservation* of *Favoured Races in the Struggle for Life*. This last has been otherwise expressed by Herbert Spencer as 'the Survival of the Fittest.'

It was the promulgation of this hypothesis of the mode of the evolutionary process that aroused the students of other sciences to the importance of evolution in explaining the methods or modes of the changes in operation.

Before the publication of Darwin's theory in 1859 the subject of evolution was discussed; but the discussion centered on the question whether evolution had ever taken place at all, and not on how it had operated in the genesis of species. Powerful and convincing arguments in support of evolution had been adduced by Herbert Spencer and others before the publication of Darwin's *Origin* of *Species*, yet these were for the most part unknown to the general public.

When this *mode* of the evolutionary process was first formulated by Darwin, it soon attracted almost universal attention. It was taken up by many able and zealous naturalists, and has permeated the whole field of biology,

and even has been applied to explain mental and social phenomena. The failure of pre-Darwinian theories to gain general acceptance was doubtless due to prejudice, as well as to the powerful influence of Cuvier.

Though previous theories rendered it highly probable that modifications had occurred, they all failed, as Darwin pointed out, to show how the modification of one species from another could take place 'so as to acquire the perfection of structure and the co-adaptation which justly excited our admiration,' since the potency of the environment, or of external conditions, of habit, of evolution, of the organism itself, etc., all alike successively broke down.

Darwin finding every theory hitherto advanced unsatisfactory, set himself to the task of accounting for the origin of species on facts acquired by much study and wide experience. He specially devoted himself to what was the weakest point in all former theories, viz., the explanation of adaptation. He says: 'Commencing in 1837, after five years' work, I allowed myself to speculate on the subject, and drew up some short notes; these I enlarged in 1844 into a sketch of the conclusions which seemed to me probable; from that time to the present day I have steadily pursued the same object.' This was written in 1859, and might not have been published even then, had he not received a paper from A. R. Wallace (then exploring the Malay Archipelago) in which views identical with his own were expressed.

Darwin's voyage as naturalist on board the 'Beagle' (an interesting account of which he has published), nearly sixty years ago (1832), enabled him to visit countries wide apart, collect specimens, and make valuable geological observations. Among other results of this most interesting voyage, is his celebrated treatise *On the Structure and Distribution of Coral Reefs*; though his conclusions regarding coral reefs have recently been subjected to adverse criticism. It is a remarkable fact that, as has been stated, Mr. Wallace, from his researches in the Malay Archipelago,

had also arrived at the conclusion, in 1844, that species owed their origin to natural selection. But it may be remarked that other great scientific discoveries have been made independently by more than one man of scientific eminence; the independent discovery of Neptune by Adams in England and Le Verrier in France, by different methods, being a notable example.

Some of the objections advanced against the Darwinian theory will be mentioned later on.

It was when naturalist on board the *Beagle* that Darwin was much struck with the facts he observed in regard to the distribution of animals and plants. This led him to devote his attention specially to the origin of species and the explanation of adaptations.

It was in the year following the publication of his first sketch that he published a fuller abstract, intending later on to give a much more detailed exposition of the facts upon which he based his conclusions. This abstract soon became famous as the *Origin of Species*. The last edition was published during the author's life in 1880, and contains a full exposition of his views, in language which no one interested in any branch of science can fail to understand and admire. Darwin, with the object of giving insight into the means of modifications, begins with an account of the variations of plants and animals under domestication. This part he subsequently elaborated and published as a separate work.

He points out that though all plants and animals show some degree of modification and variation, this is shown especially among domesticated species, owing to their new and less uniform conditions of life.

The whole organisation may be directly influenced by these new conditions; or separate parts only may be affected, and the variation may on rare occasions be definite, as when size increases with increased quantity of food, or when the quality of food produces change of colour. The action of the conditions may also be indirect,

as is exemplified by the fact that the powers of reproduction are influenced by new conditions. The effect produced by changed habits may be inherited. This is the case as regards the common duck; for the leg-bones weigh proportionately more, and the wing-bones less than those of the wild variety, for the simple reason that the domestic duck flies less and walks more.

Some mammals acquire drooping ears, since in a tame state they have not to be constantly on the alert for enemies, and drop the habit of pricking their ears in a state of alarm.

It is usual to find that one variation is correlated with others; thus pigeons with long beaks have small feet, and those with large feet have short beaks.

The widely-spread belief that domestic races revert or go back to their original condition, or the stock from which they had originally descended, is quite unsupported by any basis of fact. The truth is, all variations tend to be inherited. With the exception of the less uniform variations in domestic than in wild species—the difference being often much more pronounced in some single point—and, except that the domestic varieties are fertile when crossed, there is no well-defined difference between these varieties and true species.

If, therefore, such varieties as the many different and distinct breeds of the dog can be shown to have descended from a single wild species, there cannot fail to arise very great doubt as to the unchangeableness of closely allied natural species, such as foxes.

But though it seems that the many breeds of the dog have descended from several wild species, and those of cattle from two or three, yet our fowls, ducks, rabbits, etc., have all descended from a single ancestral species.

Great significance attaches to the case of pigeons, from the fact that the differences between pouter, fantail, carrier, and tumbler are so remarkable both externally and internally. The differences are so great that had any

ornithologist met with them in the wild state, he would have been compelled to consider them not merely as distinct species, but as well-defined and distinct genera.

It is easier to believe that any group of birds found in nature can have come from the same stock than that this is the case with the different kinds of pigeons. It has, however, been clearly proved that all these are descended from the common rock-dove (*Columba livia*); from this it is plain that those who admit the descent of the domestic pigeon from the rock-dove should be cautious in denying that this may be the case with wild ones. Domesticated races all exhibit modifications or adaptations to man's fancy rather than to their own benefit. This is due to man's power of selection; nature gives successive varieties, and man accumulates these for the purpose of making for himself useful breeds. Even in a single lifetime man often modifies the characters to such an extent that they may differ more than the distinct species of the same genera; this is seen in the case of sheep, cattle, roses, and dahlias.

The unconscious selection, which results from breeders of cattle trying to possess and breed the best animals, is still more important than conscious selection.

Two flocks of Leicestershire sheep, kept equally pure, after fifty years appeared as quite different varieties. It is because these accumulated changes take place at so slow a rate that so little is known about the origin of domestic races; and where man is incapable of accumulating them, such as in regions inhabited by savages, no plants are found worth immediate cultivation.

Human selection is assisted (1) by keeping large numbers, since the larger the number the more frequent the variation; (2) by preventing free intercrossing, because some species vary more than others.

### Variation under Nature.

Individual differences exist among all similar organisms to a wider extent than is usually supposed. In reality no

two blades of grass are precisely alike, and far more striking differences often occur, such as when several varieties are found existing in the same sex. Between these, but much oftener between forms which botanists and zoologists rank as true species, intermediate forms may occur. It is also to be kept in mind that no agreement about the definition of species (*i.e.* the amount of difference needed to give any two forms separate rank) has ever been come to. This is evident if one compare different handbooks of the flora of a country.

In the British flora there are about two hundred disputed forms; and the opinions of the botanists of the greatest reputation may be the only criterion. It is only when a genus is imperfectly known, and its species founded upon a few specimens, that it appears clearly limited, but with more complete knowledge intermediate forms are found, and doubts increase as to the specific limit.

The terms *species* and *variety* are in this way arbitrarily given to individuals more or less closely resembling one another. It will thus be seen that individual differences are of the greatest importance as the initial step towards sub-species, and in the next stage to species; though extinction may arrest the process in operation.

The species which present the greatest amount of variation are those which have the widest geographical range, or are most widely diffused in their own territory, or which consist of the largest number of individuals. In the genera of each country possessing the largest number of species, these may vary more frequently than the species of the smaller genera; and in many respects the species of large genera exhibit a strong analogy with varieties; and this analogy is only intelligible on the supposition that they at one time existed as mere varieties themselves.

### Struggle for Existence.

It is well known that all organised beings tend to increase with great rapidity, so that if the increase were not checked the earth would soon be covered with the progeny of a

single pair. Both calculation and actual observations prove this. For example, rabbits have increased to an extraordinary extent since they were first introduced to Australia and New Zealand, and the same is the case with thistles. Some organisms are reproducing themselves at such a rate, that (although all their offspring cannot escape destruction from their enemies, or if they did, could not get food) there must necessarily be a perpetual struggle for existence either of one individual with another of the same species, or for the external conditions necessary for their existence.

It is most difficult to specify the checks which keep down undue increase, since they are so obscure and vary in each case. In all cases the want of food forms the extreme limit.

As a rule the youngest organisms suffer most; seedlings, for instance, are destroyed in great numbers. Thus in a patch of land purposely dug and kept clean so as to prevent the occurrence of any choking, 295 out of 357 seedling weeds were destroyed, chiefly by slugs and insects. The stock of game on an estate depends chiefly upon the destruction of vermin. Climate moreover is of the greatest importance, and the periodic recurrence of seasons of extreme cold and drought acts as a most effective check. A severe winter sometimes destroys as many as four-fifths of the birds in a locality. When numbers have increased to the utmost limits consistent with a supply of food, they may be very much thinned by the occurrence of epidemics. If, however, there were not a large number in each species it would soon become extinct.

In illustration of the complex relations of animals and plants to each other, it may be mentioned that the planting of a part of a heath with Scotch fir leads to a profound alteration in its fauna and flora, while the growth of these firs is again wholly dependent upon the exclusion of cattle.[1]

Many flowers depend for their fertilisation upon the

[1] Cattle browse down the seedlings and prevent their growth.

visit of a particular insect, *e.g.*, red clover on humble-bees. But bees are destroyed by field mice and consequently protected by cats, 'hence not only no bees, no clover, but also the more cats the more clover!'

The struggle for life is most severe between individuals and varieties of the same species, and between species of the same genus, since these fill the same space in the economy of nature; for this reason we see the brown rat supplanting the black, and the hive-bee supplanting its Australian congener.

The structure of every living being is related to that of the others with which it enters into competition, or from which it seeks to escape, or on which it preys.

Individuals of the same species would, in circumstances adverse to the species, be subject to the same adverse influences; and in struggling against these only the fittest might survive. Again, if the animals on which the carnivora prey were capable of continually escaping, the carnivora would become extinct. It is quite possible that many species have perished owing to want of adaptation when new conditions have arisen.

### Natural Selection.

It has been seen that in the hands of man great variations are brought about both in animals and plants, and it may be asked, Can this principle apply under nature? Now there must be kept in mind (1) the constant occurrence of variation; (2) the infinite complexity of the relations in which organisms stand to each other and to the physical conditions of life; and therefore (3) what infinitely varied diversities of structure might be useful to each being under changing conditions of life. It cannot well be supposed, considering that variations useful to man have occurred, that in the course of generations no variations useful to the individual in the struggle for life have taken place.

It is not an essential part of the argument to explain the causes of the variations; it is enough to know that they

occur, and that they are in some way useful to the individual in the battle for existence. A great many more individuals are born than can possibly survive, and those that do survive must possess some advantage over those that perish. The survivors may be said to be those selected by nature. Variations of an injurious character bring about the destruction of those possessing them. This may not be a pleasant aspect of nature nor one consistent with what we might desire. So much, however, is obscure to us in regard to the plan of nature that we are never entitled to condemn a theory consistent with facts, however it may jar on preconceived notions. Besides, in the course of evolution in the organic world, all things are tending towards improvement; and it must not be forgotten that the extinction of individuals with injurious variations takes place in the initial stage of their existence.

The preservation of favourable variations and the extinction of injurious ones are termed Natural Selection or the Survival of the Fittest. Suppose a country, for example, to undergo a change of climate, the number of its denizens would change, and some of the species would become extinct. These changes would have their effect on the remaining species, new races might come into the country, bringing about further changes. The native inhabitants of no country are perfectly adapted to their conditions and fitted to cope with competitors; for some foreigners have taken possession of every country, and the inevitable conclusion follows that had the natives been perfectly adapted to their conditions the foreigners would have been successfully resisted.

Seeing then that human selection has been efficient in producing such great results, can it be doubted that natural selection has been equally, though in a less rapid degree, effective?

Human selection is limited to mere external and visible characteristics which are solely beneficial to man; its action is regular and continued for a comparatively short period.

Natural selection acts solely for the good of the individual itself, on the whole machinery of its life, and without intermission throughout countless ages. It is no serious objection that its action may be, from its insignificance, imperceptible to man. We know that great changes have taken place in the distribution of land and water on the earth's surface by means of agencies still in operation. The different geological formations are the history of those tremendous changes, and the skilful geologist and palæontologist can read the history, though he cannot fix the dates. The inconceivable length of time demanded for the gradual and uniform production of these changes staggers the imagination.

We have only to conceive the agency of natural selection operating through almost infinite time, and the objection to its potency in the evolutionary process becomes quite invalid and captious.

Natural selection leads to the improvement of every creature in adapting its structure more and more to the conditions of its existence, and in most cases leads to what must be regarded as an advancement of the organism, though lowly organised beings may continue to exist as long as they are well fitted for their conditions.

Natural selection may modify the egg, seed, or young, exactly as it does the adult, and these modifications which take place in the egg, seed, or young may modify the adult, just as modifications in the adult affect the young.

Sexual selection has to be considered along with natural selection.

The most vigorous males have the most progeny, and these are most able to hold their own in the struggle for life.

It is well known that female birds select the most melodious and beautiful males, and this doubtless produces a marked effect on the offspring.

The theory of natural selection may, in special cases, be applied, (1) to explain the evolution of the swift varieties

of wolves resembling the greyhound; (2) to explain the origin and the excretion of nectar in flowers; its use to insects in transferring pollen from flower to flower, so as to bring about intercrossing and its advantages; and the resultant modification and adaptation of flower and insect to each other by the preservation of advantageous variations.

Mr. Darwin also discusses the circumstances favourable to the production of new forms by means of natural selection.

These are mainly great variability, large numbers of individuals, the complex effects of intercrossing, and isolation in small areas; yet these small isolated areas may be extended over large continental areas, especially if these vary in altitude; and considerable lapse of time. Rare species are shown to be in process of extinction.

The divergence of character in domestic breeds is largely due to the fact that fanciers do not and will not admire a medium standard, but like extremes: and this applies throughout nature, from the circumstance that the more diversified the descendants from any species become in structure, constitution, and habits, the better fitted will they be to take possession of many widely diversified places in nature, and in this way be enabled to increase in numbers. To take the case of a carnivorous animal that has reached the limit of the numbers its territory will support, it is evident that any further increase is possible only by its varying descendants seizing places formerly occupied by other animals. This, of course, must be equally true of all species, and is proved to be true in regard to plants.

The greatest amount of life can be supported by help of great diversity in structure; hence in small isolated areas, where the competition is severe, the inhabitants vary extremely in structure. Mr Darwin discusses the probable effects of the action of natural selection through divergence and extinction on the descendants of a common ancestor.

This is illustrated by a diagram which takes the form of a genealogical tree, 'the great tree of life which fills with its dead and broken branches the crust of the earth, and covers the surface with its ever-branching and beautiful ramifications.'

### Laws of Variation.

It has been already mentioned that the causes of most variations are as yet unknown, but it would appear that the same laws have acted in bringing about the smaller differences between varieties of the same species and the greater differences between species of the same genus.

Change of conditions occasionally induce definite and permanent effects; habit, use, and disuse are powerful in their effects. Specific characters are more variable than generic, and characters that differentiate varieties vary more than either specific or generic.

Rudimentary organs are highly variable. Species that are closely related and that are of similar constitution and subjected to similar influences, present analogous variations, and not unfrequently exhibit characters incapable of explanation except as reversions to those of their ancient progenitors, as, for instance, zebra-like stripes on horses, or wood-pigeon markings on fantail, tumblers, and other birds.

### Difficulties and Objections.

In the last edition of the *Origin of Species*, Mr. Darwin devotes four chapters to the discussion of the objection which had been advanced against his theory between 1859 and 1880, and points out with great force and clearness the difficulties which he himself feels. There are (1) the definiteness of species and the rarity of transitional forms; (2) the enormous extent of modifications in habits and structure assumed by the theory, and the seeming improbability that natural selection should produce on the one hand an organ of such trivial importance as the tail of a giraffe, and on the other hand such a

wonderful organ as the eye; (3) the acquirement through natural selection of such wonderful instincts as those of the bee; (4) the sterility of crossed species and the fertility of crossed varieties. For a full discussion of these the latest edition of the *Origin of Species* should be read.

It may be here stated that since Darwin's death a vast amount of discussion has taken place as regards the potency of natural selection alone to account for the origin of species. These discussions will be found in the writings of Professor Patrick Geddes, Dr. Romanes, and others; and the most recent in the work of an American writer, Mr. David Syme, entitled *Darwin in the Balance*.

In reference to the objection urged that no complete transitional forms have been found, it must be remembered that the geological record is very imperfect.

Assuming that an enormous number of intermediate varieties, which formed links between existing and remote ancestral forms, has been exterminated, it has been asked, Why is every geological formation not full of these links? Why are they not found in every collection of fossils, so that the gradational forms might be actually seen?

This last is one of the most common and plausible objections to the theory, and is often advanced as a complete extinguisher to any further discussion on the subject. Geologists, whether they believe in the theory of natural selection or not, are fully aware of the great imperfection of the geological record: only a small portion of the strata of the globe has been geologically explored with any minuteness; only certain classes of beings have been fossilised, and the number of fossil specimens and species up to the present time forms an exceedingly small fraction of the number which must have disappeared, even during a single formation. For example, the Malay Archipelago represents in area the formation best known to palæontologists, its present condition represents that of Europe during the period that the strata of Europe were being deposited; its fauna and flora are not surpassed in rich-

ness, yet if all the species were collected that ever existed there, they would afford an exceedingly imperfect representation of the natural history of the world. Only a few species are preserved at all, and most of them are very far from being complete. Sinking of the ground is necessary for the accumulation of rich deposits; since this could not take place on an elevated area, great intervals of time must have elapsed between successive formations, so that during periods of elevation, when the variations would be most numerous, the record is most imperfect. Besides this, geological formations have not been continuously deposited; the duration of specific forms most probably exceeds that of each formation; migrations have taken place on a large scale, species that range over large areas are most variable, and, therefore, oftenest give rise to new species; at first, variations have been confined to one locality; and, lastly, it is highly probable that periods of modification are short in comparison with periods of permanence. From these facts it is clear that large numbers of varieties cannot be found, and any intermediate or linking varieties would be set down as distinct species; for it is impossible that the whole chain can be permanently restored.

The geological record is indeed a history of the world, written in a changing dialect, fragmentary and exceedingly imperfect. Of this history we possess but fragmentary chapters of the last volume, embracing only a few countries of the world. The other chapters are lost in the far back past whose dim shadow is reflected on their pages.

### Geological Succession of Organic Beings.

*(Distribution in time.)*

Although no complete series of connecting links have been found, the facts of palæontology are in admirable agreement with the theory of natural selection.

New species appear slowly, and in succession; they change at different rates and in different degrees; old forms become

rare, then disappear for ever; dominant forms spread and vary, their descendants displacing inferior groups, so that after a long period of time the world's productions are apparently changed at the same time. The most ancient forms differ most widely from those now living, and yet not seldom exhibit characters intermediate between groups now widely divergent; and, what is of profound significance, they resemble in a remarkable degree the embryos of the more recent and more highly specialised animals belonging to the same classes.

These laws, and more especially the law of the succession of the same types within the same areas during the more recent geological periods, and especially between the Tertiary period and the present time—as, for example, fossil and recent marsupials in Australia, and edentates in South America—become quite intelligible on the principle of inheritance.

Since 1859, the date of the publication of the *Origin of Species*, the researches of palæontologists have continued to furnish most emphatic testimony in favour of these views.

Professor Huxley, in a lecture delivered in 1880, entitled 'Science and Culture,' compares our present knowledge of the mammalian Tertiary fauna with that of 1859. He says that the results of the researches of Gaudry, Marsh, and Filhol are as if zoologists were to become acquainted with an unknown country as rich in new forms as Brazil or South Africa once were to Europeans.

Gaudry has discovéred the intermediate stages by which civets passed into hyenas; Filhol has unearthed still more remote carnivora, and more remarkable still, Professor Marsh, of the United States, has found a complete series of forms between the horse and the simplest five-toed ungulates!

Darwin also believed that the distinct line of demarcation which separates birds from all other vertebrates is due to the extinction of a long line of progenitors con-

necting them with reptiles. This was in 1859 a mere assumption. In 1862 the long-billed and distinctly reptilian bird Archeopteryx was discovered; and in 1875 Marsh discovered certain birds belonging to the cretaceous formation, one of which (Hesperornis) with teeth set in a groove, the other (Ichthyornis) had teeth set in sockets and bi-concave vertebræ. In addition to these reptilian birds, bird-like reptiles have been discovered, and Darwin's assumption has thus been most completely verified.

Crocodiles have been traced from ancestral forms; and amongst the invertebrates, ammonites, trilobites, etc., have been arranged in series, and important evidence is furnished by 'persistent types,' such as Ceratodus, Beryx, Nautilus, etc., which have survived without much doubt by ordinary generation, with little or no change, since remote geological periods. For these reasons Huxley truly asserts that 'on evidence of palæontology the evolution of many existing forms of animal life from their predecessors is no longer an hypothesis but an historical fact; it is only the nature of the physiological factors which is still open to discussion.'

More recent discoveries tend still further to strengthen the doctrine of the evolution of organic beings. Lowly organised fishes have recently been discovered in the lower Silurian sandstones near Cañon City, Colorado. Before this discovery, 'the sudden appearance of swarms of armour-plated fishes in the Devonian beds, without any inkling of their coming, except it might be a few scales in the Upper Ludlow strata, was a puzzle over which the anti-Darwinians lost no opportunity of chuckling. For, they contended, if there was anything in evolution, then the precipitate spring from shells and sponges to vertebrate animals of complex structure could not have been accomplished without the intermediate links being present in the Silurian. These links are now unearthed; and Mr. Walcot, of the United States Geological Survey, who has made the discovery, thinks that most likely a

fuller examination of the still deeper Cambrian formations may result in disinterring types intermediate between the backboneless and the backboned forms of life.'

*Geographical Distribution.*—The similarity and dissimilarity of the inhabitants of various regions of the globe cannot be set down to the sameness or differences of climate or other physical conditions, but both are strikingly related to the absence or presence of hindrances to migration between these regions. Within the same area there is found to be a very striking affinity among the species, though these differ from place to place. It would appear that species have arisen in separate definite centres; the exceptions to this being due to migration and dispersal, followed by change of climate as well as by geographical changes.

The arguments based on physiological and distributional phenomena having been briefly summarised, allusion will now be made to the arguments furnished by morphology. These are four, and are derived (*a*) from Classification, (*b*) Homologies, (*c*) Embryology, (*d*) Rudimentary Organs.

(*a*) *Classification.*—Naturalists arrange their species, genera, and families on what is termed the Natural System. In botany the classification of plants most in use was formerly that adopted by Linnæus, the celebrated Swedish botanist, and named the Linnæan System. The natural system is now the one in general use; and this system, from the fact of it being termed 'natural,' must have reference to something deeper than mere superficial similarity. If it is assumed that this classification is founded on the fact that it reveals the plan of creation, then it can logically be termed natural.

The main principle which prevails in classifying organic beings in groups, subordinate under other groups—individuals under varieties, and these again under species, species under genera, genera under families, families under orders, and these under a few grand classes—certainly does not appear to be based on the plan of

creation; since it admits the existence of variations through modification of structure both in animals and plants.

The nature of the relationship of the various groups is based on what is termed true affinity. Mere superficial resemblances are rejected by naturalists. A high value is set upon prevalent and constant structures, whether these may be of use, or, as in the case of rudimentary organs, of no use whatever. The bat is popularly classed as a bird, owing to its power of flight from the possession of wing-like members; but naturalists know that the so-called wings of the bat are essentially different from the wings of birds.

From the fact that the whale lives in the sea and is shaped like a fish, it is popularly and erroneously named a fish. The difficulties of classification in the vegetable kingdom are so great that even at the present time the classification adopted is merely provisional. Until the life-history of each individual is known, especially in the lower groups, no system of classification can be said to be other than tentative. The life-history of the individuals which form a group is absolutely essential to a complete and final classification. Merely artificial resemblances are misleading as a basis of classification. The whale, as has been stated, owing to its fish-like form, on the score of superficial resemblance, is popularly classed among the fishes. Its true affinity, however, is determined by its circulatory and respiratory system, and it, and other fish-like forms, are, for these reasons, classed among the mammalia. Classification proceeds on similar lines all through the animal and vegetable kingdoms, and the theory of the common descent of allied forms with modifications through variations affords the only possible explanation of the natural system. The principle of descent is employed in linking all the sexes, ages, forms, and varieties of the same species, though these are often widely apart, and differ from each other in structure; as,

for example, in the common case of alternations of generations.

This principle has only to be extended to common descent, with variations from ancestral forms, in order to render the meaning of the origin of the Natural System intelligible.

(*b*) *Homology.*—It is well known that the members of the same class, quite irrespective of their habits of life, resemble each other in the plan of organisation. The human hand, the digging paw of the mole, the leg of the horse, the paddle of the porpoise, and the bat's wing, are known by anatomists to be all constructed on the same pattern, bone corresponding to bone. The same is the case as regards the hind limb.

There is great variety in the character of the mouths of insects, *e.g.*, the long spiral trunk of the moth and the huge jaws of the beetle—nevertheless these are formed by modifications of an upper lip, mandibles, and two pairs of maxillæ. The same holds good in the varieties of the limbs of crustaceans and the flowers of plants; and indeed in the organs of every class of beings.

*The Conformity to Type.*—This is 'powerfully suggestive of true relationship, of inheritance from a common ancestor.' It is undeniably most easily understood when explained in terms of the evolutionary theory, and this adds considerable strength to the theory. It has been attempted to explain this unity of plan by supposing it due to utility; but this explanation is at variance with facts, since organs of identical use, as, for instance, the wings of a bird and those of a butterfly, in many cases do not conform to the type at all.

This conformity to type has also been attributed to a unity of design; but this unity is not seldom completely lost, instead of, as it ought to be, continually maintained; but even if this unity of design were not frequently lost in highly specialised forms, but always existed, it would irresistibly suggest unity of descent, and would in this case only serve to mislead the anatomist.

*Serial Homology* has also to be explained. The unity of type which is found in comparing the various parts and organs in the same individual is termed serial homology. The remarkably complex and varied jaws and legs of a lobster, or the very different leaves, as, for example, sepals, petals, stamens, and pistils of a flower, are all found in the former case to be simple modifications of a limb, and in the latter modifications of a simple leaf. These metamorphoses are not only seen in comparison, but can actually be seen to occur during the development of each individual. If the term metamorphosis is not to be also applied in the same sense to species, it seems difficult to avoid the conclusion that species have always remained fixed. Knowing that this is not the case, the metamorphoses may be assumed to have arisen in past time through natural selection and transmission of variations advantageous to the individual.

*Development.*—Mention has already been made of the most significant fact, that the serially homologous parts in the same individual are like each other during the early embryonic stage. This is also true of the homologous organs in animals, which, like the bat, horse, and porpoise may, in the adult condition, be widely different. The resemblance of the embryos of species belonging to the same class, and in the adult condition very distinct, is so great that Von Baer could not tell whether two specimens which were not labelled were lizards, birds, or mammals. This remarkable law of embryonic resemblance holds widely.

The embryo often retains within the egg structures which are perfectly useless either during the embryonic state, or at any later period of life; such as the transitory gills of birds or mammals; while larvæ (*e.g.* insects), which are dependent on themselves for their needs, undergo thorough secondary adaptations (*i.e.* the adaptations occur during their larval state) to the outward conditions.

Development proceeds from the general to the special,

that is, the organisation becomes more advanced, and better adapted to the surrounding conditions.

In some cases and in peculiar conditions degeneration may occur.

These facts can all be explained on the principle of successive slight variations, not necessarily or, as a rule, supervening very early in life, and inherited at a corresponding period; it is therefore highly probable that most embryonic stages more or less completely represent the progenitor of the group in its adult state. This most remarkable fact raises the study of embryology to one of the greatest interest.

*Rudimentary Organs.*—Rudimentary, abortive, and atrophied organs, which are perfectly useless, are nevertheless so extremely common that they occur in every one of the higher animals. As examples may be mentioned the mammæ of male mammals, the wings of many birds, the hind legs of boas, the teeth of fœtal whales, and the upper incisors of unborn calves. It is quite impossible to explain these organs on any other theory than as existing in a less specialised form of development as useful organs.

Darwin's theory was greatly attacked on the ground of its being inimical to religion. He very convincingly contends (*a*) that the theory of evolution by natural selection is no more inimical to religion than the theory of gravitation, against which the same objection was strongly raised; (*b*) he points out its revolutionary influence on the studies of all departments of natural history; (*c*) on psychology; (*d*) on the origin of man and his history; (*e*) on the theories of future progress. In this connection we would quote the words with which Darwin concludes his *Origin of Species*:—

'It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing in the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other,

and dependent on each other in so complex a manner, have all been produced by laws acting around us. These laws, taken in the largest sense, being Growth and Reproduction; Inheritance, which is almost implied by reproduction; Variability from the indirect and direct action of the conditions of life, and from use and disuse; a Ratio of Increase so high as to lead to a Struggle for Life, and as a consequence to Natural Selection, entailing Divergence of character and the Extinction of less-improved forms. Thus, from the war of nature, from famine and death, the most exalted object which we are capable of conceiving, namely, the production of the higher animals, directly follows. There is a grandeur in this view of life, with its several powers, having been originally breathed by the Creator into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning, endless forms most beautiful and most wonderful have been, and are being, evolved.'

A full record of the controversies to which the appearance of the *Origin of Species* gave rise, and of the rapid and wide-spread acceptance of the theory of natural selection will be found in the *Life of Darwin*.

Darwin proposed to expand the *Origin of Species*; but this expansion was only carried out as far as the subject of the first chapter, entitled 'Variations under Domestication.' His other works, viz.: *Variation of Animals and Plants under Domestication*, *Fertilisation of Orchids*, *Forms of Flowers*, *Insectivorous Plants*, *Climbing Plants*, and *The Power of Movement in Plants*, though not expansions of the *Origin*, greatly developed Darwin's favourite study of adaptations, and strengthened his general theory, as well as gave to the study of botany a degree of interest and fascination, which have done more to advance its progress than it is possible to estimate. The difficulties which he felt that the phenomenon of bee and ant society presented to his theory led him onwards to the complex problems of mind and language; and from that to the question

of the origin of man. As a result of his progress in the application of his theory, we have the *Descent of Man* and the *Expressions of the Emotions*.

As has been stated, Darwin's theory of natural selection is not universally accepted. This, however, may not be due to any radical defects, but rather to the difficulties which further knowledge will be able to remove. One of the most serious objections was made by Fleeming Jenkin, who laid stress on the tendency to swamping any individual variation however advantageous through inter-crossing. Darwin devotes considerable space to discussing Mr. Mivart's *Genesis of Species*, and his replies may be found in the latest edition of the *Origin*.

Professor Huxley says in his essay on Darwin's life, 'I venture to affirm that so far as all my knowledge goes, all the ingenuity and all the learning of hostile critics have not enabled them to adduce a single fact of which it can be said, This is one irreconcilable with the Darwinian theory.' Professor Ray Lankester has recently affirmed that, 'since its first publication in 1859, the history of Darwin's theory has been one of continuous and decisive conquest, so that at the present day it is universally accepted as the central, all-embracing doctrine of zoological and botanical science.'

Professor Patrick Geddes, from whom so many facts on this subject have been taken, says in reference to the above:

'As a matter of fact, however, this "universal acceptance" is not without its universally distributed exceptions. Some of Darwin's contemporaries have withheld their adhesion, *e.g.*, Virchow in Germany, Owen and Cleland in Britain, and the older French naturalists. Nor can the critical and controversial writings of Mivart, the Duke of Argyll, Samuel Butler, and others, be wholly ignored.

'Constructive criticism is also busy. On the one hand certainly we have the ultra-Darwinian speculations of Weismann warmly accepted by Lankester and others; but on the other hand, attempts are again being made, and

with increasing frequency, to re-state the theory of Evolution more or less completely in non-Darwinian terms. Thus following up the doubt which occasionally troubled Mr. Darwin's recent years, that he had assigned too little importance to the modifying factors of use and disuse, of environment, etc., we have Mr. Spencer re-entering the field. In America an active Neo-Lamarckian school has also arisen, which lacks neither knowledge nor thoughtfulness. In Germany we owe new contributive efforts to Nägeli and Semper, and more recently to Eimer: while in Britain complementary hypotheses have been propounded by Romanes, Sutton, Gulick, Geddes, etc. But such proposed contributions to the evolutionary theory fall rather to be treated under Evolution.'

It may be added that Darwin's theory has given rise to a vast mass of literature too great to be read except by specialists. The subject is too important to be passed over in any course of scientific reading. Darwin's theory has given an impetus to the philosophical study of organic beings, as well as to that of the development of the physical universe, and added immensely to our knowledge. It is therefore important that every one interested in science should have a clear idea of the meaning of the theory which is so often greatly misunderstood. Vague assertions are often attributed to Darwin by persons who have never read his books. Considering that Huxley, who is a host in himself, substantially accepts the theory, there cannot be much doubt that natural selection is the chief factor in the evolutionary process.

Reasoning on this, as on other subjects without practical knowledge, may often mislead; and until more convincing facts have been brought forward, Darwin's theory will hold the field; and even though it may be in future temporarily eclipsed, it is quite conceivable that it will again shine forth as a beacon light, bearing lasting testimony to the unwearied labours and great genius of its illustrious exponent.

# MIMICRY

# MIMICRY

IN ordinary language a person who can imitate the accent, manner of talking, and acting of another is said to be a good mimic. In biology, however, the term mimicry is used in a metaphorical sense, being applied to the resemblance which one species of animal or plant frequently shows to another. This resemblance is usually of a protective character. It is evident that if the resemblance which a defenceless species of animal often has to a species well furnished with natural offensive and defensive weapons were a mere freak of nature, no satisfactory and philosophical explanation of the phenomenon could be given.

Scientific investigators have to lay aside their wonder, and laboriously set about finding a solution to the most intricate and puzzling phenomena both in natural and physical science.

Mimicry was first used by Mr. W. H. Bates to denote the advantageous and generally protective resemblance assumed by one species of animal or plant to another.

It will be seen further on that the resemblance is not confined to one species of animal to another species of animal, and one species of plant to a plant of quite a distinct species, but that it also exists between animals and plants.

Mr. A. R. Wallace, who, by his most patient and skilful researches in the domain of animal life, has clearly defined and limited the term mimicry as applied in biology, says: 'A certain species of plant or animal pôssesses some special means of defence from its enemies, such as a

sting, a powerful and disagreeable odour, a nauseous taste, or a hard integument or covering. Some other species, inhabiting the same district or part of it, and not itself provided with the same means of defence, closely resembles the first species in all external points of form and colour, though often very different in structure and unrelated in the biological order.'

In South America there are certain butterflies, the *Heliconidæ,* which are remarkable for the variety and beauty of their colours; but they are incapable of rapid and sustained flight, and would for this reason fall an easy prey to insect-eating birds. Their wings, however, are never found among those rejected by insectivorous birds—in places where the remains of other butterflies frequently cover the ground. The *Heliconidæ* possess a powerfully disagreeable and pungent odour, which is so little volatile as to cling to the fingers for several days after handling one of these insects. Mr. Wallace inferred from this that they have a disagreeable taste, and would not on that account be eaten by birds. This was sub sequently found by Mr. Belt to be the case.

Belonging to the family of the *Pieridæ,* which is quite distinct from the family of the *Heliconidæ,* and the greater number of which are white, there is a genus of small butterfly named *Leptalis,* which is eaten by birds. Some species of the genus *Leptalis* are white, like their allies among the *Pieridæ,* but the majority of the *Leptales* have an exact resemblance to some species of the *Heliconidæ* as far as regards the peculiar shape and colour of their wings.

The structure of the two families is completely different; in spite of this the resemblance is so strikingly close that both the experienced entomologists Mr. Bates and Mr. Wallace, often at the time of capture mistook the one for the other, and only discovered their mistake by a closer examination. This has been looked upon as the most typical example of true mimicry, and is interesting from

the fact that it is the first instance to which the term mimicry was applied.

It is necessary to distinguish carefully between true mimicry and several similar though superficial modes of resemblance which occur among organic beings. Several orchids resemble flies or spiders, but this is merely a case of accidental resemblance.

Among animals of a higher order than insects mimicry very seldom occurs.

Amongst mammals, all of which belong to the vertebrates, mimicry is seldom found, and it is supposed that only one genuine case has been observed.

*Cladobates*, an insect-eating genus found in the Malayan region, includes many species which closely resemble squirrels both in size and colour, as well as in regard to the bushiness and position of the tail.

It is supposed by Mr. Wallace that *Cladobates*, owing to its resemblance to the harmless fruit-eating squirrel, may be enabled to approach insects and birds upon which it lives.

Cuckoos bear a considerable resemblance to hawks; the cuckoo tribe being weak and defenceless will in this way be enabled to elude the voracious hawks.

There is a genus of dull-coloured birds in Australia and the Moluccas named *Tropidorhynchus*. These birds are large, active, and strong, with powerful claws and sharp beaks. They congregate in flocks, and are remarkably aggressive, driving away crows and even hawks.

In these same countries a genus of the group orioles lives, named *Mimeta*. These are much weaker than their allies the golden orioles, and besides are devoid of their brilliant colours, being usually olive-green or brown. It is a very common thing to find species of the *Mimeta* resembling *Tropidorhynchi* living on the same island.

The *Tropidorhynchus bouruensis* and *Mimeta bouruensis* are both found in the island of Bouru; the latter of which mimics the former as described by Mr. Wallace:

'The upper and under surfaces of the two birds are exactly of the same tints of dark and light brown. The *Tropidorhynchus* has a large, bare, black patch round the eyes; this is copied in the *Mimeta* by a patch of black feathers. The top of the head of the *Tropidorhynchus* has a scaly appearance from the narrow scaly-formed feathers, which are imitated by the broader feathers of the *Mimeta*, having a dusky line down each. The *Tropidorhynchus* has a pale ruff, formed of curious recurved feathers on the nape (which has given the whole genus the name of friar birds); this is represented in the *Mimeta* by a pale band in the same position. Lastly the bill of the *Tropidorhynchus* is raised into a protuberant keel at the base, and that of the *Mimeta* has the same character, although it is not a common one in the genus.' The result is that when superficially examined the birds seem to be identical, though possessed of important structural differences, and placed wide apart in any natural arrangement.

Mr. Wallace mentions some curious cases of mimicry among reptiles, where a venomous tropical genus of snakes, *Elaps*, belonging to America, is closely mimicked by several genera of harmless snakes.

It is in a special degree among insects that cases of mimicry are most frequently found.

Genuine cases of mimicry are not so easily shown to exist among plants. The resemblance between white dead nettle (*Lamium album*) and the stinging nettle, as well as between other labiates and the stinging nettle, may be considered to be a case of real mimicry as defined above.

The true stinging nettles are avoided by animals, owing to their possession of stinging hairs, which contain an acid fluid capable of causing pain and producing blisters.

It would be clearly of advantage to another plant to resemble one possessing such defensive armour as the stinging nettle.

There is another labiate *Ajuga ophrydis* of South Africa

mentioned by Mr. Mansel Weale. This labiate closely resembles an orchid, and for this reason insects may be induced to visit the flower and thus fertilise it.

Mr. Worthington Smith, the eminent fungologist, has found three rare British fungi, each accompanying common species, which they closely resembled; and one of the common species has a bitter nauseous taste. In this case we have an example of genuine mimicry. . . .

Dr. Hans Meyer has given, in his valuable work, *Across East African Glaciers*, from which we have already quoted (p. 99), some very striking instances of mimicry. He says:—

'The similarity for the purpose of protection of the majority of the great mammals, *i.e.* the likeness of the colour of their coats, and partly also of their external appearance, to the features and colours of the regions which they inhabit must strike every traveller with astonishment.

'At a small distance, the hartebeest (antelope), when stationary, is really not distinguishable from red ant-heaps which everywhere abound; the long-legged and long-necked giraffe cannot be distinguished from the dead trunk of a mimosa, the zebra from a grey-brown clump of grass and thorn-scrub, the rhinoceros from a fallen trunk of a tree. It is only when they move that they can be distinguished. Nature has also extended this protective mimicry (Schutzspiel) to the small insects; and perhaps for this reason they often escape the eye specially in search of them; for butterflies and grasshoppers look like dry twigs, the cicadæ like leaf-stalks, the spiders like thorns, the phasmodæ like bare twigs, beetles like small lumps of earth and small stones, moths like mosses and lichens.

'This protective mimicry is manifested not only in regard to the colours and forms of the animals, but also as regards their movements, or their manner of standing still, and in their preference for certain localities appropriate to their disguise. There is protection everywhere; protection

against climatic extremes and against animal foes; such varied and abundant protection as could only be developed by natural selection in a primeval continent like Africa.'

In spite of the voluminous literature of 'animal mimicry' since Bates first published his classical memoir on the subject, the exact nature of the process whereby insects and other creatures 'mimic' (though that is not the appropriate word) the appearance of other species is still far from being understood. All we know is that this power, this resemblance of a beetle or a butterfly to the ground upon which it sits, the sticks among which it creeps, or the leaves among which it flutters, helps to save it from destruction, while it is a decided advantage to it to 'mimic' another insect which is sedulously avoided by birds. The latest observations in this by-way of zoology are as curious as any yet made. It is found, for instance, that an American spider (*Cyrtarachne*) takes the semblance of a little land-shell very abundant in the localities which it frequents; and that another species (*Thomisus aleatorius*) remarkable for the length of its fore-legs, so fastens itself on the stems of grasses as to be nearly indistinguishable from the spikelets.

Some observations, for which we are indebted to M. Heckel of Marseilles, throw a good deal of light on the origin of mimicry, at least so far as the assumption of protective coloration is concerned. There is a spider (*Thomisus onustus*) very common in the south of France, which conceals itself in the flower of a species of wild convolvulus for the purpose of trapping two kinds of fly on which it feeds. This convolvulus is found in three principal varieties: white, pink with deeper spots of the same hue, and light pink forms with a slight greenishness on the external wall of the flower. Each of these three varieties is visited by the spider. But the varieties of spider conform in hue to the varieties of the flower, and each confines itself to the one which is most protective to it. If, however, the animal is confined to a *Dahlia*

*versicolor*, it conforms to the hue of its new abode—that is, the pink one turns to red, and, in like manner, if transferred to the yellow snapdragon, it takes the colour of this flower. None of the varieties of spider mentioned are permanent. They change in shade as the shade of their host changes, and when pink, white, green, and yellow varieties are confined together in a box they all become nearly white.

The question of protective coloration in fishes has of late received some light which compels a revision of our former theories on the subject. It has usually been held that the colour of fishes is of the mimicry order—that is, it has been acquired for the purpose of deceiving their enemies. Trout will very commonly take the hue of the river bottom over which they swim, and, as every one knows, it is difficult to detect a flounder or other flat fish at rest, though when it turns over the white under-surface of its body instantly reveals the creature's presence. It has, however, been lately shown by experiments in the Marine Biological Station at Plymouth that the hue of the upper-surface is due to the action of light. For when a sole was kept in a raised glass case, with light directed upwards from below, pigment formed on the white side, and began to be absorbed on the one hitherto exposed to the same agent.

We are indebted to the literary supplement of the London *Daily Chronicle* for the interesting facts contained in the last three paragraphs of this article, and have to acknowledge that we have received valuable assistance from the same weekly supplement in regard to sources of information bearing on kindred subjects.

# EVOLUTION, OR DEVELOPMENT IN CHEMISTRY

# EVOLUTION OR DEVELOPMENT IN CHEMISTRY

EVERY one knows that there are different elements existing in the earth. The majority of these elements are only found in the earth in a state of combination with other elements. Most of the iron which is so widely distributed has to undergo a process of separation from other elements with which it is generally found in combination in the ores; the same is the case with silver and the great majority of the metals; though gold is found in a state of purity. The elements already discovered amount to about seventy in number, and are popularly divided into metals and non-metals. It must not, however, be supposed that there is any well-defined line of separation between the metals and non-metals; for it is sometimes difficult to say to which division some of the elements belong. All matter or 'stuff' is made up of elements, and these elements combine with each other in certain definite proportions by weight to form the different kinds of substances of which the whole universe is composed. The ultimate particles which combine to form plants and animals consist of elements as well as those that enter into the composition of inorganic compounds.

It is known that these elements combine in certain fixed proportions by weight to form compounds. Water, for example, is composed of two elements, viz., oxygen and hydrogen. If eighteen grammes or eighteen grains of water are taken, and if these eighteen grammes or eighteen grains of water are decomposed or split up into

their constituent elements, it will be found that there are sixteen grammes or grains of oxygen and two of hydrogen. Eighteen grammes of water are thus composed of sixteen grammes of oxygen and two grammes of hydrogen, or hydrogen and oxygen exist in water in the ratio of 1 to 8. This will be found to be the case in every sample of pure water.

This invariable relation between the weights of oxygen and hydrogen existing in water has been proved more fully by synthesis, or the formation of water from oxygen and hydrogen. An account of the methods employed will be found in the article on water.

The elements may occur in combination in various proportions. Nitrogen, for example, combines with hydrogen in the ratio of 14 to 3 by weight; and this is the invariable ratio found in ammonia gas. The combinations between nitrogen and oxygen are highly instructive. The first compound is named nitrogen monoxide, or, popularly, laughing gas, from its effect on the system when inhaled.

This compound consists of oxygen and nitrogen in the ratio of twenty-eight parts by weight of nitrogen to sixteen parts by weight of oxygen. The ratio might be expressed as 7 : 4. The next oxide of nitrogen, called nitrogen dioxide, consists of twenty-eight parts of nitrogen and thirty-two parts by weight of oxygen, or the ratio is 28 : 32, or 7 : 8. The next, or nitrogen trioxide, contains twenty-eight of nitrogen to forty-eight of oxygen, or the ratio is 28 : 48, or 7 : 12; the next contains twenty-eight of nitrogen to sixty-four of oxygen, or the ratio is 28 : 64, or 7 : 16; finally nitrogen pentoxide contains twenty-eight parts by weight of nitrogen to eighty parts of oxygen, or the ratio is 7 : 20.

It is carefully to be observed from the above ratios, viz., 7 : 4; 7 : 8; 7 : 12; 7 : 16; 7 : 20, that the ratio of the nitrogen to the oxygen diminishes regularly, *i.e.* the denominators of the fractions forming the ratios increase by 4, never by 2, 3, 5, or any number but 4.

Similar relations exist between the elements forming all other compounds.

It has been proved experimentally that oxygen, roughly speaking, is sixteen times as heavy as hydrogen—hydrogen being taken as the unit.

One gramme of hydrogen at 0° C., and under a pressure of 76 centimetres of mercury occupies a volume equal to nearly 11·16 litres (a little over 681 cubic inches). Under precisely similar conditions, sixteen grammes of oxygen occupy 11·16 litres.

Now when oxygen and hydrogen combine to form water it is found that 22·32 litres of hydrogen combine exactly with 11·16 litres of oxygen, or two volumes of hydrogen combine with one volume oxygen. The measure adopted has no effect on the result. Two litres of hydrogen combine with one litre of oxygen, or two cubic inches of hydrogen with one of oxygen. If 11·16 litres be taken as the unit volume, this is simply owing to the fact that one gramme of hydrogen at the normal temperature and pressure occupies this volume. If one litre of hydrogen be taken as the unit volume, its weight will, under the normal conditions of temperature and pressure, amount to 0·0896 gramme; and if a cubic inch be taken its weight will, under similar conditions, amount to 0·00114 gramme, or 0·0176 grain. Thus since it is known that the volume of oxygen is nearly sixteen times as heavy as the volume of hydrogen, the weight of a volume of oxygen corresponding to a given volume of hydrogen can always be found by multiplying the weight of the given volume of hydrogen by 16, or more correctly by 15·96.

There are in every sample of water two parts by weight of hydrogen to sixteen of oxygen. The ratio 2 : 16 is constant. The ratio 2 : 16 = 1 : 8, and it may asked why do we not say that eight parts by weight of oxygen combine with one part of hydrogen to form water? The reason for this will be given shortly.

It may here be stated that the chemical elements are

represented by symbols. O stands for oxygen, H for hydrogen, N for nitrogen, and so on.

It has already been shown that nitrogen and oxygen form five distinct compounds, and that the amount of oxygen contained in the compounds containing more oxygen is always divisible by the amount in the compounds containing less oxygen; in other words, the greater amount of oxygen is always a multiple of the less. This is an example of what is called the *Law of Chemical Combination in Multiple Proportion.*

This law is true in all the numerous cases in which two or more elements combine to form several compounds, and was first enunciated by John Dalton, and is the expression of well-established experimental facts. Dalton was not satisfied with the mere establishment of the law, but endeavoured to account for it by his celebrated *Atomic Theory*. This theory has already been productive of a vast amount of interesting discussion and far-reaching results.

The atomic theory assumes that matter is made up of minute indivisible particles, called atoms, from the Greek *atomoi*, indivisible particles. These atoms do not all possess the same weight, and the relation between their weights is represented by the combining weights of the elements. These combining weights are, in accordance with the atomic theory, designated the *atomic weights* of the elements.

We have seen that the ratio of hydrogen to oxygen by weight, which enters into the composition of water, is 2 : 16, or 1 : 8. Chemical compounds, as has been said, are for the sake of brevity represented by symbols. Water, for instance, is represented by $H_2O$, *i.e.* two parts by weight of hydrogen to sixteen of oxygen. The formula $H_2O$ means that the hydrogen and oxygen are to be added together: thus eighteen grammes of water or $H_2O = H_2 + O$ or $2 + 16$. It may be asked, since $2 : 16 = 1 : 8$, why water is not represented by the formula HO instead

of $H_2O$? and in fact water was formerly represented by HO. The atomic weight of hydrogen—the lightest of the elements—has always been taken as the unit, and if water was expressed by HO, the atomic weight of oxygen would have to be eight instead of sixteen. There are many reasons for assuming that the atomic weight of oxygen is sixteen, or that the atom of oxygen weighs sixteen times as much as the atom of hydrogen.

One of the reasons is connected with the combining volumes of gases. It has been experimentally proved that the densities of all the elements known in the gaseous state are identical with their atomic weights. Now two volumes of hydrogen combine with one volume of oxygen to form water. Avogadro in 1811 assumed that the number of particles into which a substance splits up in its conversion into the gaseous state is the same for equal volumes of all gases without exception under the same pressure and at the same temperature. These particles are called molecules—a molecule consisting of a number of atoms. Now since one volume of oxygen is sixteen times as heavy as an equal volume of hydrogen, and since the molecule of hydrogen contains the same number of atoms as the molecule of oxygen, it follows that the molecule of oxygen is sixteen times as heavy as the molecule of hydrogen, and the atom of oxygen sixteen times as heavy as the atom of hydrogen. The proper formula for water would thus appear to be $H_2O$ and not HO. Before proceeding further it will be well to give a list of the elements with their symbols and atomic weights.[1]

| Names. | Symbols. | Atomic or combining weights. |
|---|---|---|
| Aluminium, . . . | Al . . . . . . | 27 |
| Antimony,. . . | Sb (from Lat. *stibium*) | 121 |
| Arsenic, . . . . | As . . . . . . | 74·9 |

[1] The atomic weights in this list are those given by Roscoe and Schorlemmer in their *Treatise on Chemistry*.

| Names. | Symbols. | Atomic or combining weights. |
|---|---|---|
| Barium, | Ba | 136·8 |
| Beryllium, | Be | 9·1 |
| Bismuth, | Bi | 207·5 |
| Boron, | B | 11 |
| Bromine, | Br | 79·75 |
| Cadmium, | Cd | 111·9 |
| Cæsium, | Cs | 132·5 |
| Calcium, | Ca | 39·9 |
| Carbon, | C | 11·97 |
| Cerium, | Ce | 139·9 |
| Chlorine, | Cl | 35·37 |
| Chromium, | Cr | 52·1 |
| Cobalt, | Co | 58·7 |
| Copper, | Cu (from Lat. *cuprum*) | 63·1 |
| Fluorine, | F | 19·1 |
| Gallium, | G | 69·8 |
| Germanium, | Ge | 72·3 |
| Gold, | Au (from Lat. *aurum*) | 196·8 |
| Hydrogen, | H | 1 |
| Indium, | In | 113·4 |
| Iodine, | I | 126·53 |
| Iridium, | Ir | 192·7 |
| Iron, | Fe (from Lat. *ferrum*) | 55·9 |
| Lanthanum, | La | 138 |
| Lead, | Pb (from Lat. *plumbum*) | 206·4 |
| Lithium, | Li | 7·01 |
| Magnesium, | Mg | 24·2 |
| Manganese, | Mn | 54·9 |
| Mercury, | Hg (fr. Lat. *hydrargyrus*) | 199·8 |
| Molybdenum, | Mo | 95·6 |
| Nickel, | Ni | 58·6 |
| Niobium, | Nb | 94 |
| Nitrogen, | N | 14·01 |
| Osmium, | Os | 191 |
| Oxygen, | O | 15·96 |
| Palladium, | Pd | 106·2 |
| Phosphorus, | P | 30·96 |
| Platinum, | Pt | 194·5 |
| Potassium, | K (from Lat. *kalium*) | 39·04 |
| Rhodium, | Rh | 104·1 |

| Names. | Symbols. | Atomic or combining weights. |
|---|---|---|
| Silver, . . . | Ag (Lat. *argentum*) . | 107·66 |
| Sodium, . . . | Na (Lat. *natrium*) . | 22·99 |
| Strontium, . . . | Sr . . . . . | 87·2 |
| Sulphur, . . . | S . . . . . | 31·98 |
| Thallium, . . . | Tl . . . . . | 205·6 |
| Tin, . . . . | Sn (Lat. *stannum*) . | 118·6 |
| Zinc, . . . . | Zn . . . . . | 65·1 |

It is only necessary for the proper understanding of what follows to explain one or two words that will sometimes be used. By the term *oxide* is meant a compound formed by an element with oxygen. All the elements with the exception of fluorine combine with oxygen and form oxides. When coal is burned oxides are formed, viz. oxides of carbon and hydrogen. When bodies unite with oxygen and in so doing evolve light and heat they are said to burn.

It should also be stated that certain elements have a greater tendency to combine with each other than others. Thus hydrogen and chlorine gases when exposed to the sun's rays combine with explosive force. Again such elements as nitrogen and oxygen can only be made to combine directly with one another with difficulty. The tendency of elements to combine together is termed *chemical affinity*, and is most strongly manifested by bodies that differ considerably in their atomic weights.

The other terms necessary to be explained are *acids*, *bases*, and *salts*.

Two well-known acids are sulphuric acid and nitric acid. Sulphuric acid is represented by the formula $H_2SO_2$, where $H_2$ represents two atoms of hydrogen, S one atom of sulphur, and $O_4$ four atoms of oxygen. It must clearly be understood that any portion of sulphuric acid, though invariably represented by $H_2SO_4$, may be of any weight whatever. When the letters are spoken of as representing the number of atoms, it simply means the relative weights of each element contained in the com-

pound. Thus ninety-eight tons of sulphuric acid contain two tons of hydrogen, thirty-two of sulphur, and sixty-four of oxygen. The same relative weights would exist whatever the amount taken. Suppose half a gramme of sulphuric acid taken, then there would be $\frac{1}{98}$ gramme of hydrogen, $\frac{16}{98}$ gramme of sulphur, and $\frac{32}{98}$ gramme of oxygen. The absolute weights of the atoms are of course unknown, but the weights of the substances which form any chemical compound are always proportional to the absolute weights of the atoms. Nitric acid is represented by the formula $HNO_3$ where the formula shows that hydrogen is present in the proportion of the weight of one of its atoms, nitrogen also in the proportion of the weight of one of its atoms, and oxygen in the proportion of three of its atoms.

Nearly all the acids are soluble in water; they have a sour or acid taste, and possess the property of turning blue litmus-solution red. All acids contain hydrogen combined either with one element or a group of elements, which usually, though not always, contains oxygen. Such acids as hydrochloric contain no oxygen; and in contradistinction to the acids devoid of oxygen, such acids as nitric and sulphuric are termed *oxy-acids*. When the hydrogen in these acids is replaced by a metal, the acid character of the substance disappears and a *salt* is formed.

If zinc is added, for example, to dilute sulphuric acid a salt named zinc sulphate is formed. Salts are also formed when certain hydroxides, or compounds of a metal formed by the union of the metal with hydrogen and oxygen, are brought in contact with an acid. The same takes place when certain oxides of the metals are brought in contact with acids.

If potassium is added to water, part of the hydrogen of the water is liberated and at the same time ignited, and a hydroxide of potassium is formed. The potassium has displaced half of the hydrogen, and has taken its place. This substance is named caustic potash and possesses alkaline

properties. It turns red litmus-solution blue, and when added to nitric acid the sour taste of the acid disappears at a certain point, and a neutral salt is formed. The soluble hydroxides which act thus on acids are termed *alkalies.* In the same way many oxides of the metals called *basic oxides* or *bases* act upon acids to form salts. With these explanations it will not be difficult to understand what follows in regard to the constitution of atoms.

There has lately been much speculation about the nature of atoms. As a matter of fact the atoms are beyond the field of direct observation, and their actual existence is therefore a matter of inference; but there can be very little doubt regarding the validity of this inference, since it is only possible to explain a large number of chemical and physical phenomena on the assumption of the existence of atoms. In fact every chemical theory is based on the supposed existence of separate and distinctive particles of matter possessing definite and constant weights.

It was at one time considered impossible to arrive at any conclusion regarding the absolute weight of an atom; all that was needed practically was a knowledge of the relative weights of atoms. Hydrogen being taken as the unit atom, it mattered not what its actual weight might be provided it was definitely known how many times as heavy any other atom was. For instance, if a gramme of hydrogen occupied 11·16 litres under 76 centimetres of mercury and at a temperature of 0°C., and the same volume of oxygen under similar conditions of temperature and pressure weighed sixteen grammes, then it was rightly assumed that the atom of oxygen is sixteen times as heavy as the atom of hydrogen.

It has been asserted that the atoms are infinitely small, *i.e.* that they do not occupy any space, but are only centres of force or points around which movements take place.

This idea, however, has lost all support from its inherent improbability, as well as in consequence of new investiga-

tions in the domain of molecular physics. These investigations have proved the actual existence of molecules, and that these molecules have dimensions. Now a molecule is made up of two or more atoms, and since molecules possess both dimension and weight it follows that atoms must do the same.

From the theoretical investigation of the most varied effects of molecular action it has been found possible to arrive at least at an approximate determination of the limit-dimensions of the molecules of different elements.

In 1870, Sir William Thomson, in a popular lecture, pointed out that the results obtained from perfectly distinct investigations showed a remarkable amount of agreement which added greatly to the probability of their correctness.

The results arrived at show that the diameter of a molecule of any substance can never be smaller than the fifty-millionth part of a millimetre, but is often considerably larger. It would necessitate the use of too technical language to explain the methods employed in working out these results; but without this explanation there need be no hestitation in accepting them as correct. It may be stated that a quadrillion molecules of hydrogen weigh about four grammes. From this the weight of the molecule of any other substance which obeys Avogadro's law can easily be calculated. It is, however, not possible from this result to calculate the weight of an atom, since the number of atoms which form a molecule is not known. It is probable that just as these substances which occupy space are made up of molecules or particles of the first order, and molecules are composed of atoms, or particles of the second order, so atoms are composed of particles of matter of the third order. Were not this the case, it would be necessary to assume that as many elementary forms of matter existed as there are chemical elements. This, to say the least, is very highly improbable.

Prout, as far back as 1815, supposed that the primordial

matter of which all the elements are composed is hydrogen; and he further stated that all the elements were multiples of hydrogen. This, however, is not correct; but the divergence has been explained to be possibly due to the hydrogen atoms, when combined to form other atoms, having in addition to the primordial matter varying quantities of ether which may not be quite unaffected by gravity. This ether is supposed to fill all space, and is the medium by means of which light, heat, etc. are propagated. Its existence is as certain as that of any other substance. Ethereal vibrations have actually been made manifest by Hertz. An account of the remarkable experiments of Hertz was given by Professor Fitzgerald in an address to the British Association at Bath, in the autumn of 1888.

The supposition that the ether may have weight is of course very different from that of its existence, the former being only a probably correct supposition, the latter a fact.

It must also be remembered that the correct atomic weights of many of the elements are not yet known; and when the atomic weights have been still more accurately determined it may probably be found that they are not far from being multiples of hydrogen; but even supposing that Prout's law does not quite hold, the deviations from it can be explained in the manner already stated.

Mr. Crookes, in a lecture delivered in 1887, and entitled *Genesis of the Elements* has given weighty reasons for believing that the so-called atoms are in reality compounds. Other distinguished men of science have entertained similar ideas regarding the elements; for example, John Dalton, who enunciated the Atomic theory, Professor Faraday, Dr. Gladstone, Dr. Mills, Professor Stokes, and Professor Norman Lockyer.

It may be asked, Why trouble about atoms, why not take them as they are? But the same objection might be urged against all and every kind of speculation. Besides, knowledge is valuable apart from its immediate results; and when speculation is founded on knowledge it never

fails to add facts of the greatest possible importance and value to those already acquired. Mr. Crookes says: 'In these our times of restless inquiry we cannot help asking, What are these elements, whence do they come, what is their signification? We cannot but feel that unless some approach to an answer to these questions can be found, our chemistry after all is something profoundly unsatisfactory. The elements perplex us in our researches, baffle us in our speculations, and haunt us in our very dreams. They stretch like an unknown sea before us, mocking, mystifying, and murmuring strange revelations and possibilities.'

When such language is used by one who has spent and is still spending his life in the service of science, and whose researches in connection with 'radiant matter,' to say nothing of his discovery of thallium, have thrown so much light on the more hidden properties of matter, the compound nature of the elements cannot be rejected on the grounds of mere speculation unsupported by facts.

Chemists are well aware that certain bodies have a much greater affinity for one another than others. For example, hydrogen and chlorine when mixed can only be kept from combining when excluded from light. If the mixture be exposed to the direct rays of the sun (as already mentioned on p. 167) an explosive combination takes place.

On the other hand, if nitrogen and oxygen be mixed, they can with difficulty be made to combine at all.

Hydrogen and chlorine have a very strong affinity. Whereas the affinity between nitrogen and oxygen is slender. Now bodies that have a strong affinity for one another always differ considerably in atomic weight. Bodies again whose atomic weights are nearly equal are held together by very slender affinity. Bodies whose affinity is very slender are difficult to separate; this especially refers to the metals. The difficulties here do not lie in the strength of the affinities to be overcome, but in the fact that almost all reagents act alike on the one substance as on the other.

Mr. Crookes has devoted much time to the investigation of the 'rare earths.' These earths are only found in a few minerals such as samarskite and gadiolinite, and these have only been found in a few localities.

The method of separating the elements existing in these rare earths is termed 'fractionation.'

The earths are dissolved and the solution is rendered very dilute. Ammonia is then added in such quantity that it precipitates one-half of the bases present. Owing to the great degree of dilution some hours must elapse before the liquid becomes turbid. The liquid is then filtered, and by this process the earths are divided into two parts no longer identical. It has yet to be decided whether the earth separated is simple or not. The fractionation process cannot be employed for deciding this.

The method employed by Crookes is what he has appropriately named the 'radiant matter test.' The substance is placed in a vacuum of about the millionth of an atmosphere, or the amount of atmospheric pressure only amounts to about 0·0002 inch of mercury. This is by no means the lowest vacuum obtainable, though it is found to be most suitable for the radiant matter test. When what is in electricity called an induction spark acts on the rare earths in this vacuum they become phosphorescent, or behave differently from what they would do under a greater or smaller pressure. The examination of the operations of the phosphorescing is undertaken by means of the spectroscope. It would be impossible to give a popular account of the various reasons deduced from the spectra of the rare earths for concluding that they are composed of several elements.

About four years ago, yttrium was considered to be an elementary body, but according to Crookes it is composed of molecules differing from each other in size, and in the position they occupy in the 'yttrium edifice;' though some chemists believe that the apparent compound character of yttrium is due to the presence of other elements.

It is important as bearing on the compound nature of the elements to state that A. E. Nordenskiöld has taken the crude mixture of yttria, erbia, ytterbia, etc., just as they are precipitated from the minerals which contain these rare earths. He names the mixture gadolinia; and this gadolinia, though most probably a compound substance, has invariably a constant atomic weight. Nordenskiöld says, 'Oxide of gadolinium, though it is not an oxide of a single body, but a mixture of three isomorphous oxides (*i.e.* oxides that crystallise in the same form) 'possesses a constant atomic weight.' 'We are,' he says, 'in the presence of a fact altogether new in chemistry.'

This is a case of different substances occurring in a mixture not only always together, but in the same proportions.

The same principle is applicable to all the so-called elements.

Didymium was formerly treated as an element. It was with difficulty separated from its accompanying bodies, lanthanum and cerium. Didymium was decomposed by Dr. Auer Von Welsbach into two simpler bodies; and Crookes and others have shown that the two bodies into which didymium has been separated are themselves not simple but compound.

These facts are most significant in their bearing on the compound nature of the elements. For since it has been proved that bodies hitherto considered to have been simple, and to have had a constant atomic weight, can be broken up into simpler bodies, the evidence in favour of the compound nature of all the elements whose atomic weight exceeds hydrogen (*i.e.* all the elements except hydrogen) is immensely strengthened.

It may never be possible to realise the dream of the alchemists and transmute the 'baser metals' into gold; but the delicate tests employed by distinguished men of science go far to compel the elements to disclose their history—a history dating back 'not six thousand years,

nor sixty thousand years, nor six hundred thousand years, but æons of untold millions.'

Mr. Crookes has named the primordial 'stuff' from which the elements have been formed Protyle (derived from the Greek *pro*, earlier than, and *hylē*, matter or stuff, hence protyle means stuff existing earlier than the elements).

Mr. Crookes states that in amorphous matter (*i.e.* matter without crystalline forms) we recognise a tendency to aggregation not to be identified with gravitation, since it is manifested among finely divided matter whether suspended in a medium of specific gravity superior, equal, or inferior to its own (*i.e.* in a medium or substance heavier, of the same weight, or lighter, bulk for bulk, than itself).

This agglutinative action (tendency to run together and unite) is familiar to observers of natural phenomena: clouds contracting to that appearance known as a mackerel sky, particles of carbon floating in the air, collecting, and ultimately falling as 'blacks,' and so on.

This principle may have made itself manifest in the condition of protyle. The further explanation of how the elements were formed from this is scarcely to be considered popular or easy to grasp; but Crookes supposes that hydrogen was the element first formed, and after a time another element, and so on. The longer the interval between the formation of the different elements, the more distinctive their properties.

A table is given by Mr. Crookes to illustrate the possible order of the genesis of the elements. The table here given (taken from Sir H. E. Roscoe and Professor C. Schorlemmer's *Treatise on Chemistry*) is slightly different. It is a table of the natural arrangement of the elements, in accordance with the researches of Lothar Meyer and the Russian chemist Mendelejeff, or Mendeléeff, as the name is sometimes written.

Newlands in 1862 drew attention to the fact that the properties of the elements varied periodically, but little attention was paid to his statement at the time, as

### TABLE OF THE NATURAL ARRANGE

| I | | | II | | III | | IV | |
|---|---|---|---|---|---|---|---|---|
| Hydrogen 1 | Lithium 7·01 | — | Beryllium 9·1 | — | Boron 11 | — | Carbon 11·97 | — |
| — | Sodium 22·99 | — | Magnesium 24·2 | — | — | Aluminium 27 | Silicon 28·3 | — |
| — | Potassium 39·04 | — | — | Calcium 39·9 | Scandium 44 | — | — | Titanium 48 |
| — | — | Copper 63·1 | Zinc 65·1 | — | — | Gallium 69·8 | Germanium 72·3 | — |
| — | Rubidium 85·2 | — | — | Strontium 87·2 | Yttrium 89 | — | — | Zirconium 90 |
| — | — | Silver 107·66 | Cadmium 111·9 | — | — | Indium 113·4 | Tin 118·6 | — |
| — | Caesium 132·5 | — | — | Barium 136·8 | Lanthanum 138 | — | — | Cerium 139·9 |
| — | — | — | — | — | — | — | — | Ytterbium 173 |
| — | — | Gold 196·8 | Mercury 199·8 | — | — | Thallium 205·6 | Lead 206·4 | — |
| — | — | — | — | — | — | — | — | Thorium 231 |

MENT OF THE ELEMENTS

| V | | VI | | VII | | VIII | | |
|---|---|---|---|---|---|---|---|---|
| Nitrogen 14·01 | — | Oxygen 15·96 | — | Fluorine 19·1 | — | — | — | — |
| Phosphorus 30·96 | — | Sulphur 31·98 | — | Chlorine 35·37 | — | — | — | — |
| — | Vanadium 51·2 | — | Chromium 52·1 | — | Manganese 54·9 | Iron 55·9 | Nickel 58·6 | Cobalt 58·7 |
| Arsenic 74·9 | — | Selenium 79 | — | Bromine 79·75 | — | — | — | — |
| — | Niobium 94 | — | Molybdenum 95·6 | — | Ruthenium 103 | Rhodium 104·1 | Palladium 106·2 | — |
| Antimony 121 | — | Tellurium 125 | — | Iodine 126·53 | — | — | — | — |
| — | — | — | — | — | — | — | — | — |
| — | Tantalum 182 | — | Tungsten 184 | — | Osmium 191 | Iridium 192·7 | Platinum 194·5 | — |
| Bismuth 207·5 | — | — | — | — | — | — | — | — |
| — | — | — | Uranium 239 | — | — | — | — | — |

chemists in general considered the arrangement of the elements according to their atomic weights as arbitrary and worse than useless.

The periodic law was, however, further developed by Lothar Meyer, and more especially by Mendelejeff; and it afterwards became known that a natural classification of the elements was found to exist. The difficulties which are in some cases encountered in arranging the elements according to the natural system arise from the uncertainty still existing in regard to the atomic weights of some of the elements.

The relation is shown in the table, where it will be seen that the elements may be arranged into eight principal groups, several of which may further be divided into sub-groups.

The first principal group contains the metals of the alkalies, and to this the copper group is annexed on account of the isomorphism of some of the silver salts with the salts of sodium. These also agree in forming basic oxides of the form $M_2O$ (where M stands for either of the metals in question), or oxides that form salts with acids.

The second principal group is also made up of two sub-groups (1) the metals of the magnesium group, (2) those of the calcium group, several members of which are connected owing to the isomorphism of some of their salts.

The elements which form sesquioxides (from Latin *sesqui*, more by a half, as $M_2O_3$, the symbol M representing the metal) are found in the third group. The last three elements are metals whose sulphates (of the form $M_2\ 3\ SO_4$) unite with the sulphates of the alkali metals and form alums, and connected with these are the metals of the cerium group, and belonging to this group several numbers have yet to be discovered.

The group of tetrad elements comes next (tetrad is derived from the Greek numeral *four*, and is applied to an element capable of displacing or combining with four atoms of hydrogen, or four parts of hydrogen proportional

to its atomic weight, *e.g.* $CH_4$ where carbon is a tetrad. When an element combines atom for atom with hydrogen it is named *monovalent* or a *monad*. When an element combines with two atoms of hydrogen it is termed *divalent* or a *dyad*, and when with three it is *trivalent* or a *triad*, *e.g.* HCl, Cl being a monad, $H_2O$, O being a dyad, $NH_3$, N being a triad). The group of tetrad elements is also divided into sub-groups.

The nitrogen group comes fifth, and this is closely connected with the sub-group vanadium, niobium, and tantalum. In the sixth group are two sub-groups, which are connected by their formation of isomorphous chromates (that is, salts formed by the union of a base with chromic acid), and molybdates (salts formed by the union of a base with molybdic acid) which are isomorphous with sulphates and selenates (that is, salts formed by the union of selenic acid with a base). The seventh group contains the chlorine family, and with this manganese and ruthenium are intimately connected owing to the isomorphism of the perchlorates, permanganates, and perrutheniates ($KClO_4$, perchlorate, $KMnO_4$, permanganate, $KRuO_4$, perrutheniate). Osmium is doubtfully placed in this group owing to its agreement with the other metals of the group in being easily oxidisable.

In the eighth group occur the iron family and the other members of the platinum group. These are related to the members of the seventh group on account of the analogy existing between the compounds of these metals, and the cyanides of iron (compounds of iron and hydrocyanic or prussic acid) and cobaltamine salts (compounds of cobalt with ammonia). These by no means exhaust the analogies which are exhibited in the arrangement. Those elements, which belong to different groups, and which were formerly classed together owing to their similarity in chemical as well as physical properties, are, as might be anticipated, found close together in the natural system. Lithium and magnesium both agree in forming carbonates that dissolve

with difficulty, and boron and silicon, which form analogous fluorides, are found not far apart from one another. Lead is placed near thallium; cadmium is in the same line as indium, and tin and vanadium next to phosphorus.

If the table is examined, it will be found that matter becomes endowed with analogous properties when the atomic weight of an element is increased by the same or nearly the same number. Hydrogen, it will be seen, has no analogue, and therefore is supposed by Meyer to be the element from which all the others are formed. Starting from lithium, its more important properties reappear in sodium. The difference of the atomic weights of lithium and sodium is nearly fifteen, whilst another increase of about sixteen above sodium brings us to potassium, and if about forty-six be added to potassium we come to rubidium, and an addition of nearly another forty-six brings us to cæsium. Similar relations will be found to exist in the case of the other series. Thus the difference of the atomic weights of beryllium and magnesium is nearly sixteen; between calcium and strontium it is nearly forty-six. This will be found to hold between elements in each series if the one atomic weight is subtracted from the other at corresponding distances apart. For example, the difference of the atomic weights of lithium and sodium equals that of beryllium and magnesium, nitrogen and phosphorus, oxygen and sulphur, fluorine and chlorine.

As another example, the difference of the atomic weights of rubidium and cæsium equals that of strontium and barium, of yttrium and lanthanum, and so on.

Mendelejeff has enunciated this law as follows:—The *chemical properties of the elements are a periodic function of their atomic weights.* This is expressed in mathematical language; but it means that when the atomic weights vary the properties also vary, but recur at certain periods. Starting with lithium, and going on to sodium, where the properties of lithium recur, may be called a period. But it does not matter which element is made the starting

point, for when another is reached, differing from it in atomic weight by sixteen or forty-six, a period has been passed over. It is for this reason that the properties of the elements are called a periodic function of their atomic weights, since each element really begins a period.

The chemical character of an element is distinctly affected by the magnitude of its atomic weight. If groups three and four are examined, it will be found that the lower members mostly form acids when combined with oxygen, whereas the higher yield oxides that combine with acids to form salts. Elements such as aluminium, which are found in the centre, yield oxides which possess both acid and basic properties. The special character of groups six and seven is to form acids which diminish in strength in proportion as the atomic weights rise ; and in the case of groups one and two the increase of the atomic weights is accompanied by an increase of basic power.

In other groups it is found that the increase of the atomic weights is accompanied by an increase of the power of the oxides to form acids.

The atomicity or quantivalence (that is, the power of combining with or displacing one, two, three, or four atoms of hydrogen) may be considered as a function of the atomic weight. Take, for example, the first member of each of the chief groups, and the following compounds are formed with either chlorine or hydrogen (it must be borne in mind that chlorine, like hydrogen, is a monad). LiCl (lithium chloride), $BeCl_2$ (beryllium chloride, beryllium being a dyad, and therefore combining with two atoms of chlorine), $BCl_3$ (boron chloride, boron being a triad, and therefore combining with three atoms of chlorine), $CH_4$ (methane, or marsh gas, carbon being a tetrad and combining with four atoms of hydrogen ; $NH_3$ (ammonia, nitrogen being a triad and combining with three atoms of hydrogen), $OH_2$ (water, oxygen being a dyad and combining with two atoms of hydrogen), FH (hydrofluoric acid, fluorine being a monad and combining with one atom of hydrogen). It will

be seen that the quantivalence of the elements gradually rises from one to four, and again gradually decreases. Similar variation as regards quantivalence is observed in the other series, *e.g.* AgCl, (chloride of silver), $CdCl_2$ (chloride of cadmium), $InCl_3$ (chloride of indium), $SnCl_4$ (tetrachloride of tin), $SbH_3$ (antimony hydride), $TeH_2$ (telluretted hydrogen). Other chemical properties also vary with the atomic weights.

It has been shown by Mendelejeff and Lothar Meyer that not only the chemical properties, but also the physical properties of the elements are closely connected with their atomic weights.

There is a remarkably close relationship between atomic weight and atomic volume. By atomic volume is meant the quotient obtained when the atomic weight of a substance is divided by its specific gravity.

It will be seen that spaces are left in the table to be filled up by elements not yet discovered. Mendelejeff has derived the names of the missing elements from the names of the first members of the series, and for his purpose has made use of Sanscrit numbers. If we take the empty spaces in the table below boron, in a line with copper and zinc, an element is found to be wanting. In the same line, and in the column containing aluminium, the element gallium is found. This element was recently discovered by the French chemist Lecoq de Boisbaudran. Before its discovery Mendelejeff said 'ekaluminium in its properties stands between zinc and ekasilicon on the one hand, and between aluminium and indium on the other. Like the latter, it forms a sesquioxide; its atomic weight is about 68; its specific gravity about 6; and its atomic volume approaches 11·6.' These predictions have been wonderfully fulfilled, for ekaluminium, now named gallium, has an atomic weight of 69·8, specific gravity 5·9, and atomic volume of 11·8.

Ekaboron, whose atomic weight should be 44, and, like aluminium, should form a sesquioxide, turns out to be

scandium; and this metal possesses the properties which according to prediction would belong to ekaboron.

Where germanium stands in the table was formerly a blank. Before this element was discovered, Mendelejeff predicted regarding its properties, under the name ekasilicon, that it 'forms a dioxide, and occupies a position between ekalumminium and arsenic on the one hand, and between silicon and tin on the other. Its atomic weight will be about 72, its specific gravity 5·5, and its atomic volume about 13.' This is in exact accordance with the properties of germanium, whose atomic weight is 72·3, specific gravity 5·46, and its atomic volume 13·2. Doubtless the natural classification of the elements will be the only classification adopted when the exact knowledge of the atomic weights has been acquired. The fulfilment of Mendelejeff's prediction regarding the then undiscovered elements, gallium and germanium, is a proof, if proof were needed, of the profound significance of the natural arrangement of the elements.

Inorganic chemistry will become capable of being based on principles which will give it all the precision and symmetry possessed by organic. This remarkable property of the elements would, as has been stated, be a natural result of the compound nature of the atoms.

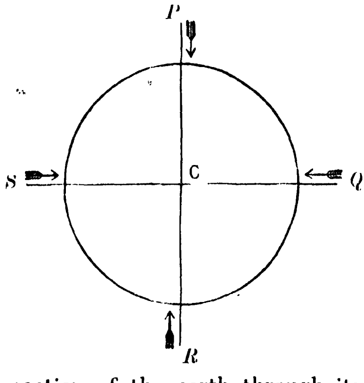
It is a consistent theory that the elements owe their different properties to the number and the arrangement of the primordial atoms which, as it were, form their edifice. A more beautiful and far-reaching theory would be difficult to conceive; and there is no reason to doubt, as is now generally admitted, that just as all organic beings have been evolved from lower and simpler forms, so all the elements have likewise been formed from one primordial substance.

# GRAVITATION

# GRAVITATION

THE principle of gravitation forms a very important factor in the explanation of many of the phenomena of nature. It constitutes the foundation of that part of astronomy which treats of the motions of the heavenly bodies. It supplies us with an explanation of the phenomena connected with the falling of bodies to the earth. It forms an interesting chapter in the history of science, if we consider the various steps by which the grand truth was finally established that every particle of matter in the universe attracts every other particle. The same principle also helps us to explain the early stages in the history of the development both of the solar system, and of other systems throughout the universe.

In illustrating the action of gravity it will be most convenient to begin with the motion of falling bodies. Every one knows from experience that a heavy body if left unsupported will fall to the ground. The force which causes the body to fall is known as that of gravitation.




In order that the reader may form a general conception of the direction of this force, let the Diagram here given represent a section of the earth through its centre, and let us suppose a spectator to be stationed in

space at a distance from the earth, sufficient to enable him to obtain a view of the entire section. If a stone or other heavy body be dropped from points outside the earth's surface, such as *P*, *Q*, *R*, *S*, the body would be seen in each case to move in the direction of the line joining the point with the earth's centre; so that from *P* the body would appear to move downward, from *R* upwards, from *Q* from right to left, and from *S* from left to right: and generally from whatever point the body falls the direction of its motion will always be from the point towards the centre of the earth. In order to specify a force completely, it is necessary to know not only its direction but also its intensity. The intensity of gravity at the earth's surface is measured by the acceleration, or change of velocity, which it produces in falling bodies in one second of time. If a body fall from rest for one second under the influence of gravity, it is found to have acquired a velocity, which if gravity were to cease would carry it over 32 feet in the next second, or its velocity has been changed from 0 to 32 feet per second. If the body fall for two seconds, it will be found to have acquired a velocity of 64 feet per second, or a velocity of 32 feet has been added to that which was acquired during the first second of the body's motion. This additional velocity of 32 feet per second is known as the acceleration due to gravity, and is the measure of its intensity at the surface of the earth.

The tendency of bodies to fall towards the earth or the attraction of the earth on matter enables us to account for its heaviness or weight. If we place a heavy body in one scale of a balance while the other scale-pan contains no counterbalancing weight, we observe that the loaded scale at once begins to descend, and if its motion were free from constraint, its fall would only be arrested on its reaching the ground. We know, however, from the ordinary process of weighing that the balance can be kept even by placing suitable weights in the opposite scale, and from

the known weight required for this purpose we obtain the weight of the body first placed in the scale of the balance. If we now suppose that bodies have no tendency to fall to the ground, or, which is the same thing, that the earth exerts no attractive force on matter, no weight would be required to maintain the equilibrium of the two scales when a substance is placed in one of them. This is equivalent to saying that in the case supposed bodies would have no weight, or that if gravity were to cease, matter would be without weight. We are thus enabled to conceive the existence of matter without weight, since the absence of gravitation does not necessarily involve the conception that matter itself has ceased to exist. The most remarkable circumstance connected with gravity is that the distance from the centre of the earth remaining the same, the intensity depends upon the magnitude of the masses, and not upon the nature of the substances. If the body be made of stone, wood, iron, water, or even air, the attraction remains the same provided the masses remain constant. In this respect gravity differs from magnetism, since magnetic attraction only shows itself in the case of a few bodies.

From this property of gravity it follows that a piece of lead and a very light body, such as a feather, if dropped at the same instant from a certain height will reach the ground together if gravity is the only force acting upon them. This can only be shown by means of a specially arranged experiment, where the two bodies can fall in a space which has been exhausted of air. If tried in a room, the experiment, it is needless to say, will fail, on account of the resistance of the air, which is greater in the case of the lighter body, thus causing it to lag behind the heavier one. The experiment may be tried in a space unexhausted of air by placing a feather on the top of a rupee, and allowing the latter to drop in such a way as to remain horizontal during its fall. Since the rupee displaces the air under the feather, the two will remain in

contact until they reach the ground. By means of experiments made on the fall of bodies in a vacuum, it has been demonstrated that 'all bodies of whatever size, shape or material, if dropped side by side at the same instant, fall side by side in a space void of air.' A body will always tend to fall to the earth, however great the height may be from which it has been dropped. The intensity of gravity does not indeed remain the same as we ascend, but decreases much more rapidly than the distance from the earth's centre increases. If we could by some means reach a height of 4000 miles, we should have doubled our distance from the centre of the earth, and the intensity of gravity would only be one quarter of the intensity at the surface of the earth, or $\frac{1}{4}$ of $32 = 8$. It is known also that the distance through which a body falls at the surface of the ground during the first second of its motion is 16 feet. At the height of 4000 miles, the distance fallen through in the first second would only be 4 feet. Again, a substance which weighed 4 lbs. on the earth, would at the above height weigh only 1 lb., and at the height of 8000 miles $\frac{1}{9}$ lb. The above facts may all be summed up in the statement that the intensity of gravity varies inversely as the square of the distance from the earth's centre. The law of universal gravitation fully stated is as follows:

Every particle of matter in the universe attracts every other particle with a force whose direction is that of the line joining the two, and whose magnitude is directly as the product of their masses, and inversely as the square of their distance from each other.

This law is the result of an induction based upon a number of facts, including the fall of bodies to the earth, and the motion of the planets in their orbits.

The above law expressed in symbols gives $f = \frac{mm'}{d^2}$, where $f$ represents the intensity of the attraction, $m$ and $m'$ the masses which mutually attract each other, and $d =$ the distance between them. As an illustration let us sup-

pose a system $m$, consisting of one particle $p$, and a system $m'$ of two particles $r$, $s$, to be situated at the distance unity from each other. Let the attraction between any two particles be represented by unity, $p$ will be pulled towards $m'$ by a force from $r$ equal to unity, and by a force from $s$ equal to unity. The system $m$ or the particle $p$ will therefore be pulled towards $m'$ or $r$, $s$, with a force represented by $2 \times 1$. Again, suppose $m$ to consist of two particles $p$, $q$, and $m'$ of three $r$, $s$, $t$; $p$ will now be pulled towards $r$, $s$, $t$ with a threefold force, $q$ also will be drawn towards $r$, $s$, $t$ with a threefold force, and, on the whole, $m$ will be drawn towards $m'$ with a twice threefold force, or $2 \times 3 = 6$. If the distance between the systems be doubled, the force in each case becomes one fourth of its former amount. When we wish to represent the earth as one of the attracting bodies, $m'$ will represent the mass of the earth, $d$ the distance of the mass $m$ from the earth's centre. The expression then becomes $g = \frac{mm'}{d^2}$. Here $m$ stands for the body which is seen to fall to the earth. The earth $m'$ ought also to move towards $m$, but since the pull of the earth on $m$ is so much greater than that of $m$ on the earth, the latter appears to be stationary. Unless the attracting bodies are of great size the intensity of this force is small, hence gravitation may be described as a very weak force. It requires the mass of the whole earth to produce the motion of falling bodies at the earth's surface, and the weight of a body is not sensibly diminished in the neighbourhood of mountain masses.

It can be shown by observation that the law of gravitation holds good in all regions of space which are accessible to us—whether on the summit of the highest mountain or at the bottom of the deepest mine. But since the greatest height to which we can ascend is very small in comparison with the radius of the earth, it is impossible from observations made in this manner to infer that in all parts of the universe the force of gravity varies inversely as the square

of the distance. Assuming the law of gravitation to be as above stated, and knowing its value at the surface of the earth, Sir Isaac Newton calculated its value at the distance of the moon, and found it to be equal to the force necessary to retain the moon in her orbit. He was thus able to deduce all the circumstances of the moon's motion round the earth, and, at the same time, to show that the force which acts between the earth and the moon is the same as that which causes bodies near the earth's surface to fall towards it. Under these circumstances it might, at first sight, be supposed that the earth ought to pull the moon down; for it seems paradoxical to state that a body such as the moon should be continually falling towards the earth without at the same time approaching any nearer. If the earth and moon were both at rest, the action of gravity would draw them together, but since the moon is already in motion, the effect of the earth's attraction is to keep the moon in her orbit instead of allowing her to move off in a straight line. Before attempting to explain this, it will be necessary to state some facts regarding the motion of bodies, and the action of force on material bodies as given in Newton's laws of motion. We require also to know the relation which exists between the distances through which a body falls under the action of gravity and the time during which it has been falling.

The first law of motion states :—

That a body continues in its state of rest or uniform motion in a straight line, except in so far as it may be compelled by impressed forces to change that state.

The second law asserts :—

That change of motion is proportional to the acting force, and takes place in the direction of the straight line in which the force acts.

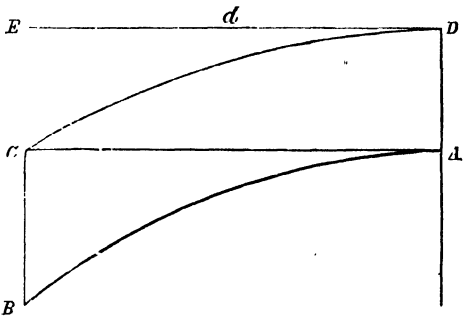
The first law was only clearly stated for the first time by Sir Isaac Newton; for the earlier observers of physical phenomena appear to have thought that the continuous action of some force was necessary to keep a moving body

in motion, and the truth that a moving body once in motion, and acted on by no force, will continue to move forward for ever made its way but slowly towards general recognition.

The second law enables us to see that a force will produce in the direction in which it acts the same effect on a body already in motion as if it had acted on the body at rest.

When a body falls under the influence of gravity, the distances through which it will fall in successive seconds have been experimentally determined, and the law of falling is sufficiently simple to be easily understood. Leaving out of account the resistance of the air, a body will fall during the first second of its motion a distance of sixteen feet; during the next second three times that distance, and during the third second five times that distance, and so on.

With the aid of the foregoing explanations the reader will be in a position to understand the following illustration of the action of gravity on a body already in motion, which has been taken in substance from Professor Newcomb's *Astronomy*.




Let the curved line *AB* represent a portion of the earth's surface, *AC* the horizontal line of sight of an observer at *A*. Owing to the curvature of the earth, the

earth's surface falls away from the horizontal line nearly eight inches in the first mile, twenty-four inches more in the second mile and so on. In five miles the fall will amount to sixteen feet. In ten miles forty-eight will be added to this, making sixty-four feet feet in all—the law being the same as that of a falling body.

Let a body be projected in the horizontal direction *DE* from the point *D*, whose height above the surface of the earth is *AD*, and let the velocity of projection be five miles per second, and suppose the body to meet with no resistance from the air. Take *d* a point on the horizontal line *DE* five miles from *D*. Since by the second law of motion gravity produces the same effect on the moving body as if it had been at rest, it will have fallen sixteen feet below the line *DE* during the first second, But since the earth at this distance curves away sixteen feet from the horizontal line, the moving body will be at the same distance from the earth as before. Suppose *E* to be the point which the body would have reached at the end of the second second, its distance below the line *DE* will now be sixty-four feet. But at this distance the earth has also curved away so as to make the point *B* sixty-four feet below *C*. Thus we see that the moving body now at *C* is at the same distance from the surface of the earth as it was at starting, although it has been falling away from the horizontal direction in which it was projected at the same rate as a falling body. As we have supposed the body to meet with no resistance from the air, it will by the first law of motion continue to move with undiminished velocity; and just as we have seen that at the end of the first and subsequent second the body is no nearer to the earth than at the beginning of its motion, so it will go on moving during the third, fourth, and every succeeding second at a constant height above the surface of the earth, since the earth curves away as fast as the projected body drops. The latter, after making a complete circuit of the earth, would arrive again at D without any

loss of velocity, and thus be in a position to make an indefinite number of revolutions round the earth. A body moving in the manner above described may be regarded as a satellite of the earth, and if the height *AD* in the figure had been 240,000 miles the revolving body would have been in the position of the moon.

In order to explain the moon's motion it was necessary to ascertain what force was needed to retain the moon in her orbit, and thus prevent her from flying off in a straight line by the first law of motion. Newton found that the deflection of the moon's path from a straight line was such as to amount to a fall of sixteen feet in one minute, the same distance as a body falls at the surface of the earth in one second. The distance through which a body falls under the action of gravity is given by the expression $S=\frac{1}{2}gt^2$ where $S=$the number of feet through which the body has fallen during the time $t$—the latter being expressed in seconds and $g=32$ at the surface of the earth. The distance through which a body falls at the surface of the earth in one second is therefore $S=\frac{1}{2}\times 32\times 1^2=16$ feet. To find the force of gravity at the distance of the moon, we have seen that this body falls through 16 feet in 60 seconds. Representing gravity by $g'$ we have $16=\frac{1}{2}g'\times 60^2$ or $g'=32/60^2=32/3600$. Comparing this with the value of gravity at the surface of the earth $g/g'=\frac{32}{\frac{32}{3600}}$ $\therefore$ $g/g'=3600/1$. Newton thus found that the force of gravity at the surface of the earth was 3600 times as great as the force which held the moon in her orbit. This number is the square of 60, which is the number of times the moon is more distant than we are from the centre of the earth. Representing our distance from the earth's centre by $r$, the distance of the moon is $60\,r$; and from the relative values of $g$ and $g'$ above given we see that when $r$ is increased to $60\,r$ gravity is $1/3600$ of its former value; in other words, the force varies inversely as the square of the distance. In this way Sir Isaac Newton found that

the force which retains the moon in her orbit is the same as that which causes a stone to fall.

The principle of gravitation is of still wider scope than has been yet indicated; for it supplies the law by which the movements of the planets can be accounted for.

Kepler, a German astronomer who lived in the latter part of the sixteenth century, had ascertained by a large number of observations that the line joining the position of a planet in its orbit to the sun describes equal areas in equal times. Accepting this fact as true, Newton showed that it could only be accounted for on the supposition that a force acting in the direction of the sun's centre was deflecting the planets from their rectilineal course. In this way the existence of gravity between the planets and the sun was clearly established. Kepler by observation had also discovered that the orbit of a planet with respect to the sun is an ellipse with the sun in one of the foci. From this law Newton proved that the intensity of the force which exists between a planet and the sun is inversely as the square of the distance. Kepler's laws were the results of observation. Sir Isaac Newton removed from them their empirical character, and showed that they must be true. Admitting the law of gravitation it can be shown that the planets must move round the sun.

With regard to the question as to what is the cause of gravity no satisfactory conclusion has as yet been reached. Le Sage supposed that space was filled with a large number of very minute bodies which he named ultramundane corpuscles. When these corpuscles impinge on a single body isolated in space, the blows thus received by the body have no tendency to produce motion in it, because, coming as these blows do from all sides, they have no tendency to push it in one direction more than in another, and the body remains at rest. When, however, there are two bodies in space they mutually screen each other on their opposing faces from the impact of the corpuscles, and as each of the bodies will thus

receive a larger number of blows from behind than in front, they will tend to move towards each other. Sir William Thomson and Clerk Maxwell have also shown how gravitation may be explained; but with regard to all the explanations which have yet been given of the origin of the force, the latter has remarked that their chief value lies in the stimulus which they will give to further investigation.

NEBULAR THEORY AND TIDAL EVOLUTION

# NEBULAR THEORY AND TIDAL EVOLUTION

VARIOUS speculations have been broached by early writers to account for the origin of the Earth and the solar system. Most of the theories being founded on no solid basis of fact were merely fanciful and therefore unworthy of serious attention.

It was not till Kant's time that any systematic attempt, founded on real knowledge, was made to give a theory of the evolution of the solar system in accordance with the recognised truths of astronomy.

In 1755, Kant published his *General Natural History and Theory of the Firmament, or Inquiry regarding the Constitution and Mechanical Origin of the Formation of the Entire Universe, treated in Accordance with the Fundamental Principles of Newton.* Kant's extensive knowledge, not only in philosophy, but in mathematics and dynamical principles, enabled him to treat the subject in a manner worthy of its great importance.

It has already been stated that the material, out of which the elements that compose the planets were evolved, was of one uniform nature. It is assumed that, instead of being collected into numerous bodies far apart, it filled all space. Mr. Crookes, as we have seen, has named this substance Protyle. This protyle by some process may be supposed to have become broken up into separate masses, and again to have broken up, and out of each mass suns and systems to have been evolved. During this process the protyle may be supposed to have been gradually chang-

ing its constitution, continuing no longer homogeneous, but gradually changing into the various elements that enter into the constitution of the Earth and other planets. These processes did not begin throughout boundless space simultaneously, but at inconceivably long intervals of time, and as Professor Green, in his lecture, entitled *The Birth and Growth of Worlds*, says: 'This double work of concentration and individualisation did not begin everywhere throughout the universe at the same time. It started at some places earlier than others, and there can be no reason for thinking that it has now ceased.

'So we should expect matter still to exist in every stage of development, and it is only reasonable to think that the work has been going on, and is now going on, and will keep going on during a future to which we can place no limit.'

Laplace, the celebrated French astronomer and mathematician, developed a hypothesis independently of Kant; and this was first published in 1796. The fuller development of Laplace's theory was published in 1824. This is the celebrated Nebular Theory, and was advanced with the view of accounting for the evolution of the solar system. It is obviously not capable of proof; but is so consistent with the known facts as to give it a high degree of probability.

The first fact of great importance favourable to the theory is that, with one or perhaps a few curious exceptions amongst the most distant bodies, the planets and moons have all a common direction of revolution round the sun, and another fact is that the great planets have their orbits in nearly the same plane. That is, the planes of their orbits are inclined to one another at small angles, and all the planets rotate about axes nearly perpendicular to the plane in which they revolve, and in the same direction as they revolve.

Laplace imagined that the sun had once a nebulous atmosphere that filled all the space now occupied by the

planets, extending to Neptune the outermost planet, distant 2,791·7 millions of miles.

The probability that such a mass must have had some movement of rotation is so great as almost to amount to certainty.

It is known that nearly all bodies contract on cooling. As this nebulous mass cooled it would contract, and it is well known that when a rotating body contracts its velocity increases. As the velocity increases the centrifugal force also increases; and in the case of a rapidly rotating nebulous mass, the velocity would eventually become so great that the centrifugal force would overcome the attraction of the centre, and a ring would become detached. As contraction goes on the velocity continues to increase and another ring becomes detached. These detached rings would not hold together but would break up and collect into a ball. The ball of course revolves in the same direction as the nebula from which it became detached, and rotates about an axis parallel to the axis round which the nebula rotates. In this way there will finally be a number of balls which revolve about a common centre, and are in the same plane rotating in the same direction about axes perpendicular to the plane.

The largest mass remains in the centre, and of course retains its heat longer than the smaller bodies.

Some of the smaller bodies when cooling and contracting may throw off smaller rings, and these contracting into balls will form moons.

The matter may be looked at from another point of view. We may begin with the sun as we find it at the present time, and reason backward to what must have been the condition in the earlier stages of the solar system. The enormous daily radiation from the sun, when properly studied, is a strong argument in favour of the nebular theory. The earth receives less than one two-thousand-millionth part of the whole radiation from the sun. We know that a heated ball of iron after a certain period,

depending on its size, and the temperature of the surrounding medium, will become cold. The heat will all have left it. Within historical times there is nothing to show that the sun is becoming colder, notwithstanding the enormous amount of heat that comes from it every day. Many attempts have been made to explain this; for it is evident that however large a mass a hot body might possess, in the course of thousands of years it must become perceptibly colder. The sun would cool some degrees every year. Attempts have been made to account for the conservation of the sun's heat by supposing that he is constantly being bombarded by showers of meteors. It has also been affirmed that the only loss of heat the sun undergoes is the amount of heat received by the planets. What the sun radiates into empty space is not heat, but only becomes heat when the radiation is absorbed by some body and the body thereby becomes heated. The space beyond our atmosphere would not absorb heat, for ether is diathermanous and is not heated by the sun's rays. Other theories have been advanced to account for the retention of the sun's heat through the ages that have already passed. We know that when coals are burned heat is radiated; but it is impossible that the heat of the sun can be kept up by any process analogous to combustion. To supply the daily radiation of the sun by combustion twenty tons of coal would need to be burned on each square foot of the sun's surface. The supply of meteors would also be inadequate to sustain the sun's heat; for it can be proved that it would need a quantity of meteors, whose collected mass was equal to the moon, to plunge into the sun daily at a high rate of speed to keep up the sun's heat. There can be little doubt but that the sun is an incandescent body (*i.e.* a body at glowing white heat) giving out heat, but that the cooling is very greatly retarded owing to the sun's huge mass and to a well-established law of heat. We know that when energy disappears in one form it is not lost but re-appears in another form. In the case of a gas,

for example, when it suddenly expands it is cooled by the process. The gas has done work by its expansion and the equivalent of this work has disappeared as heat. Were the gas forced back so as to be compressed to its original volume, the temperature would be the same as it was before expansion.

As the sun cools it of course contracts, and after the contraction the particles are nearer each other than they were before. The nearer the particles of the sun approach each other the more the energy due to their separation is lessened.

The energy thus lessened re-appears in the form of heat. The sun must according to this be slowly contracting, but while it contracts it gives forth heat. This is sufficient to account for the fact that there has been apparently no diminution of the sun's temperature within historical times.

It can be proved that to account for the conservation of the sun's present temperature its diameter dimishes four miles every century. The diameter of the sun is nearly a million of miles and it will need a considerable number of centuries before the diameter is much diminished. Going backwards we find that a thousand years ago the sun's diameter must have been forty miles greater than it is at present, and ten thousand years ago the diameter must have been four hundred miles greater than at present; a million years ago it must have been forty thousand miles greater than it is at present, and so on.

Thus looking backward we can set no limit to the growth of the sun. We can conceive it gradually extending till the orbits of the planets are successively reached.

The materials composing the sun would, owing to this huge extension, be greatly rarefied, and thus become the nebula from which the solar system originally was evolved.

Our sun is only a star; and vast though its mass is, in comparison with many other suns its mass is small.

The question has been raised whether any other system than ours presents evidence of a nebular origin.

Sir William Herschel discussed this question and brought together the evidence which bears on this point. He stated that there are regions in the heavens where a 'faint, diffused nebulosity is all that can be detected.' There are other nebulæ in which a nucleus can be detected, others in which the nucleus is quite easily observed, and others again in which the nucleus is a brilliant point like a star. It would be a natural transition from an object of this kind to a nebulous star, and equally natural for the nebulous stars to pass into the ordinary stars by gradual stages. It thus appears quite possible to suppose a series of objects beginning with the most diffused nebulosity and ending with an ordinary fixed star, or group of stars. It is of course not possible for observers to see the process in operation. The immense period of time required for such a change precludes the possibility of its ever being seen. Regarding the nebular theory, Professor Newcomb says: 'At the present time we can only say that the nebular hypothesis is indicated by the general tendencies of the laws of nature, that it has not been proved to be inconsistent with any fact, that it is almost a necessary consequence of the only theory by which we can account for the origin and conservation of the sun's heat, but that it rests on the assumption that this conservation is to be explained by the laws of nature as we now see them in operation. Should any one be sceptical as to the sufficiency of these laws to account for the present state of things, science can furnish no evidence strong enough to overthrow his doubts until the sun shall have been found growing smaller by actual measurement, or the nebulæ be actually seen to condense into stars and systems.'

Very recently a new and most fascinating chapter has been added to the history of our 'earth-moon' system. This can only be here treated very briefly, with a view to

drawing the attention of readers to this *Romance of the Moon.*

A lucid and very charming history of our earth-moon system will be found in two lectures delivered by the distinguished astronomer and mathematician, Sir Robert S. Ball, Royal Astronomer of Ireland. The lectures are entitled *Time and Tide, a Romance of the Moon.*

Without entering into any particular account of the tides, it may be stated that from the earliest times it has been known that the moon and the tides are connected.

The moon is not the sole agent which causes the tides, for the sun also is a tide-producing agent. The reason why the solar tides are much less than those caused by the moon, notwithstanding the enormously larger mass (26,000,000 times) of the sun, depends upon the law by which the efficiency of a tide-producing body is estimated. The law states that the efficiency of a tide-producing body such as the moon or sun varies according to the inverse cube of the distance. The moon's average distance from the earth is only about the $\frac{1}{386}$th part of the sun's distance.

Now, taking the mass of the moon as unity, the mass of the sun will be 26,000,000. Again, taking the distance of the sun as unity, the distance of the moon will be $\frac{1}{386}$th of the unit distance of the sun.

The tide-producing efficiency of the sun is 26,000,000 divided by $1^3$, or simply 26,000,000, as compared with 1, the mass of the moon taken as unity, divided by $(\frac{1}{386})^3$, or 1 divided by $\frac{1}{57,512,458}$, which is equal to 57, 512, 458. It will thus be seen that the efficiency of the sun in producing tides is less than half that of the moon, or the tidal efficiency of the moon is about 2·22 times as great as that of the sun. When the solar and lunar tides are coincident, they tend to produce very high tides and low tides. That is, the waters of the sea rise to a great height and recede to a great distance. These are named spring tides. When, however, the sun is so situated as to produce a low tide while the moon is raising a high tide, the result is

merely the excess of the moon's tide over the sun's; this is termed a neap tide.

The theory of the tides can only be treated mathematically; though it is possible to ascertain by observation at what period the time of 'high water' occurs at any given place. For example, if one knows the time of high water at London Bridge, the time at other ports and places of the United Kingdom may be found approximately by adding or subtracting certain periods of time termed tidal constants. It is, however, with the effects of the tides on our earth-moon system that we wish briefly here to deal.

It is generally known that the movement of the tides is attended by friction. Not only do the particles of the water rub against each other, but near the shore the water rubs against the shingle or sand. Every visitor to the seaside has heard the grating sound produced by the rubbing of the water during the ebb and flow of the tides. It is a well-known fact that friction produces heat, and hence the friction of the tides produces heat. As you will see in reading about energy, heat is a form of energy. Machinery in motion becomes heated if the friction is not practically eliminated by means of lubricants. If a piece of iron is pressed against a grindstone in rapid motion, the iron will become heated at the expense of the motion of the grindstone. Many obvious instances will occur to any one. A definite amount of heat always represents a definite amount of energy. The heat produced by the friction of the tides must also represent a definite amount of energy. This energy must be obtained from the earth-moon system, which contains two parts, the moon-energy and the earth-energy. The moon-energy consists in part of the energy due to its rotation, but for the most part of the energy due to its revolution round the earth. The energy of the earth due to its revolution round the sun is not taken into account in treating of the earth-moon system; for the moon also revolves round the sun along with the earth.

Our attention, therefore, need only be confined to the earth-energy due to its rotation, and the moon-energy due to its revolution round the earth. As a consequence of the moon turning the same face to the earth there can no longer be any tides on the moon's surface. The tides must therefore consume the energy of the earth, for the moon, having no longer any tides, can only have its moment of momentum increased at the expense of the earth's energy. The remarkable consequence deducible from this is that the rotation of the earth is becoming slower, or *the tides are increasing the length of the day.* This is a well-ascertained fact, and one of the most profound and astounding significance.

Since the moment of momentum of the earth-moon system is a constant quantity, and since the moon is incapable of transferring any moment of momentum to the earth, whatever transfer occurs must be taken from the earth.[1] The effect of this is to drive the moon farther away from the earth. While this very gradual process is going on the day continues to lengthen, owing to the rotation of the earth on its axis becoming slower.

It might be thought that since the moon causes the tides the energy expended by these tides should be contributed by the moon. This is, however, not the case, but the proof of the evidence against it is not very simple. The dynamical principle on which the solution depends was first indicated by Professor Purser of Queen's College, Belfast. The principle is general, and is founded simply on the laws of motion, and does not necessarily involve astronomical observations.

The lengthening of the day is such a slow process that even in historical times no appreciable difference in its length can be clearly proved to have taken place. Yet it

[1] Moment of momentum may be expressed as total quantity of spin. In the earth-moon system this is threefold: (1) the rotation of the earth on its axis; (2) the rotation of the moon on its axis; (3) the orbital revolution of the moon round the earth.

is as certain as any law of nature can be that the energy consumed by the tides is being taken from the energy of the rotation of the earth, and it is only the prodigious length of time required for the change to be observable that prevents us from estimating the rate of change in the length of the day.[1]

Passing over very many most interesting details in connection with the tides, we may in fancy look backwards to the time when the earth was a glowing hot molten mass. The proofs that the earth was such are numerous; but it may here be sufficient to state that volcanic eruptions afford evidence that the interior of the earth is still at a very high temperature, and that the cool crust on which we live was once a molten mass on which no life of any kind could exist. It is certain that at some particular period of the earth's history the moon formed part of the molten mass of which the earth was composed. At that early epoch of the earth's history, the time occupied by the earth in making a complete rotation was about four hours or perhaps a little less. This rapid rotation was necessarily accompanied by a powerful centrifugal force tending to cause rupture. Professor G. H. Darwin has stated that the sun's action on the molten mass of the earth would produce tides. And here it is to be observed that though at this early stage of the earth's history there was a total absence of water, yet the molten material composing the earth was susceptible to tidal impression. The sun was then the tide-producing agent. All bodies have periods in which they are disposed to undulate, and the period of the undulations depends upon the dimensions and the mass. The tides produced by the sun harmonised with the natural period of undulation of the earth, and kept on increasing in amplitude until a rupture occurred. The portions broken off formed eventually one mass: this mass being the infant moon.

[1] These results are true only on the supposition that the system is isolated from all external interferences.

These tides were, of course, not water tides but tides of the molten material of the earth, and they were assisted in causing a rupture by the centrifugal force due to the rapid rotation of the earth.

Since the moon originally formed part of the earth, it, therefore, at its birth kept on revolving round the earth, just as if it still formed part of it. At this very early epoch the moon would neither produce tides on the earth nor the earth tides on the moon. The tides produced by the moon on our earth are due to the difference in the periods of the axial rotation of the earth and the revolution of the moon round the earth. When these periods were equal, the moon and the earth turned the same face to one another, and in consequence there could be no tides either on the moon or on the earth. Tides could, therefore, have no influence either on the moon or on the earth, and so far as the tides were concerned, the earth-moon system might have continued in this state for ever.

This is named by Sir Robert S. Ball the first critical epoch in the earth-moon system. It is called a critical epoch from the absence of the ebb and flow of tides in the system, and the consequent continuation of the relative positions of the earth and moon, in so far as tides are concerned.

The condition of the earth-moon system was at the first critical epoch one of unstable equilibrium: that is, it would be exceedingly liable to change. The moon might at this epoch either have fallen back to the earth or retreated farther from it. We know that it did not fall back; and whatever cause brought it about the moon began to retreat from the earth. As the moon retreated it would cease to turn the same face to the earth; for the periods of its axial rotation and its revolution round the earth would no longer coincide. The earth and the moon no longer turned the same face to one another, tides were produced, and the relative rotation of the earth and moon would no longer be zero. By relative rotation is meant the difference

between the angular velocity of the earth and the angular velocity of the moon in its orbit.[1]

The energy of the earth-moon system at the first critical epoch was at a maximum, and any alteration in the earth-moon system diminished the energy. This diminution of energy will continue to go on until the second critical epoch, when the earth will turn the same face to the moon. The energy of the earth-moon system is then at a minimum. It cannot, therefore, become less whatever further changes occur. At the present epoch of the earth-moon system the moon always turns the same face to the earth. This is a very remarkable coincidence and cannot be supposed to be the result of chance. A physical explanation for this striking phenomenon was pointed out by Helmholtz. Without doubt this condition is the result of the work of ancient tides on the moon's surface. The tides produced on the moon by the earth were much greater than the tides produced by the moon on the earth. We know that the friction caused by the tides is slowing the rotation of the earth, and, therefore, the much higher tides produced on the moon by the earth would be still more effective in diminishing the axial rotation of the moon. This diminution of the moment of momentum due to the moon's axial rotation caused the moon to retreat farther and farther from the earth. The transference of moment of momentum took place in such a way, that as the moment of momentum of the moon's axial rotation was diminished that due to its revolution was increased. As long as the moon kept rotating round its axis in a less period of time than it needed to perform its revolution round the earth, the tides kept acting on the moon and slowing its rotation. As a

[1] Let N represent the angular velocity of the earth, and M the angular velocity of the moon in its orbit round the earth, then M—N is the expression for the relative rotation; and this, multiplied by the change in the earth's angular velocity, expresses the alteration of the energy of the system.

matter of course, the lunar tides were also increasing the period of the earth's rotation, but owing to the much smaller size of the moon, combined with the enormous tides on its surface, its rotation was reduced at a much greater rate than that of the earth; in fact the period of the moon's rotation has been increased from about four hours to rather more than twenty-seven days.[1] It is, of course, impossible even to imagine the length of time that has elapsed since the action of the tides on the moon's surface augmented its period of axial rotation to such an extent that it coincides with the period of its revolution round the earth. During the countless ages that have passed since the action of the ancient tides on the moon's surface caused it to turn the same face to the earth, the consumption of energy by the tides has been drawn from the energy stored up in the rotation of the earth. As has been said, the moment of momentum of the earth-moon system is a constant quantity, and whatever is lost by the earth must be gained by the moon.

Momentum is defined as the product of mass by velocity. Let M stand for mass and V for velocity, then MV represents the momentum. If MV is multiplied by its perpendicular distance from any point, the product is termed the *moment of momentum*.

As regards heavenly bodies, it is necessary to mention that the moment of momentum consists of two parts, one part being due to the rotation of the bodies round their axes, the other to their revolution round the sun. The momentum of a planet at any instant is the product of its mass by its velocity, and the moment of momentum of the planet may be found by multiplying the momentum by the radius of its path. The moment of momentum of rotation is more difficult to calculate. The angular velocity of rotation of the sphere is one of the factors, while the other factor involves the sphere's mass and

[1] A day is the period needed by the earth to make a complete rotation on its axis.

dimensions. As far as the moon is concerned it is the part of the moment of momentum due to its revolution round the earth that chiefly concerns us. Suppose two concentric circles, one of which is double the radius of the other, and suppose two bodies revolving round these circles, one in the inner circle and one in the outer. Let the masses of these bodies be equal, and the periods of their revolution equal; now when the radius of one circle is double the radius of another, the circumference is also double. In this case, therefore, the velocity of the outer body is double the velocity of the inner, because it passes over double the space in the same time. Let M represent the mass of each body—in this case supposed to be equal. Let V represent the velocity of the body moving in the inner circle, $r$ the radius of the inner circle, then 2V represents the velocity of the body moving in the outer circle, and $2r$ is the radius of the outer circle. The moment of momentum of the body moving in the inner circle is $MVr$, and that of the body moving in the outer circle is $M \times 2r \times 2V$ or $4MVr$.

Now the ratio of $MVr$ to $4MVr$ is that of 1 to 4.

We see from this that the moment of momentum increases as the squares of the radii.

The case we have supposed could not occur in our system. If two planets of equal mass were revolving round the sun, the one twice as far from the sun as the other, their periodic times could not be equal; for Kepler's third law tells us that the square of the periodic time is proportional to the cube of the mean distance. Suppose two planets revolving round the sun, one being three times as far from the sun as the other. Then the space described by the outer planet in its periodic time $T'$ is three times that described by the inner, in its periodic time T. If $a$ represent distance generally, then, according to Kepler's law, $\frac{a^3}{T^2}$ is a constant quantity; therefore $\frac{1^3}{T^2}=\frac{3^3}{T'^2}$ or $T'^2=T^2 \cdot 3^3$, hence $T'=5 \cdot 19T$

where T represents the periodic time of the inner planet and T′ that of the outer. It will thus be seen that though the more distant planet has three times as great a distance to traverse as the first, it needs 5·19 times as much time as the inner planet. Its velocity is therefore less than the velocity of the inner planet.[1]

And here it must be stated that velocity means distance passed over in unit of time. For example, we speak of a velocity of so many feet per second, *i.e.* uniform velocity, such as that of the planets, and the space traversed in unit time expresses the velocity.

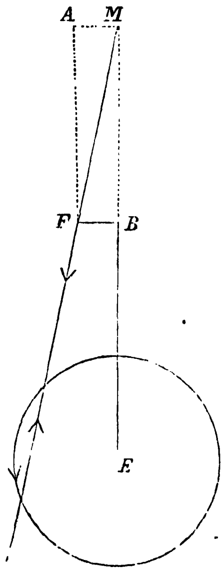
The unit space may be a foot, centimetre, yard, metre, mile, or kilometre ; the unit time a second, minute, or hour.

It will be seen that in comparing the moments of momenta of the planets which revolve round the sun, the moment of momentum of each planet is proportional to the product of its mass by the square root of its distance from the sun.

We have seen that the moment of momentum of the earth-moon system is a constant quantity. It must not be inferred from this that the energy of the earth-moon system is a constant quantity. The energy of the system is constantly diminishing. It is true that whatever moment of momentum the earth loses owing to the augmentation of its period of rotation is exactly transferred to the moon, yet the increase of energy gained by the moon by this increase of moment of momentum is not equal to the energy lost by the earth. Part of the earth's energy of rotation is dissipated in the form of heat. This fact enables us to decide from what source the tides derive their energy. If the tides got their energy from the moon, the moment of momentum or quantity of spin contributed by the moon would be lessened, and in exactly the same proportion, as the quantity of spin of the earth would be increased. This increase of spin would necessitate an increase in the speed of the earth's rotation. But the increase of energy due to the increase of the earth's rota-

[1] The orbit of a planet is not a circle but an ellipse.

tion would be greater than the diminution of energy caused by the decrease in the moon's quantity of spin. By this process, though as a matter of fact the quantity of spin would remain constant, the energy of the earth-moon system would increase; that is, the result would be that the tidal action caused an increase of energy in our system. This would amount to a species of perpetual motion, and is of course utterly absurd. Bearing in mind, therefore, that though the moment of momentum, or quantity of spin, in our earth-moon system is a constant quantity, this is by no means the case as regards the energy of the system. We find that the energy is being constantly dissipated by the action of the tides, and that this dissipation is gradually diminishing the energy of the earth-moon system, and will go on diminishing it until the earth turns the same face to the moon, that is, until the month and the day are of equal length.[1] The first critical epoch occurred when the earth and the moon moved in close proximity, each having the same face towards the other. As the moon moved away from the earth, tides began to be raised on the earth, and the length of the day began to increase as well as the length of the month. The month increased more rapidly than the day, or the moon was driven farther and farther from the earth, and therefore described a larger orbit. The action of the earth in causing the moon to retreat may be illustrated by means of the adjoining figure, taken from Sir Robert S. Ball's *Time and Tide*.



Nebular Theory.

[1] By *month* is meant the time required by the moon to make one revolution round the earth.

*E* represents the earth, and *M* represents the position of the moon. To avoid complications, the moon is represented by a point, and since the moon attracts every particle of the earth, the total effect of the attraction of the moon can be represented by a single force. We know from Newton's third law of motion that reaction is always equal and opposite to action, therefore the force of the earth on the moon is in the figure represented by an equal and opposite force. If the moon did not produce tides on the earth, the attracting force of the moon would pass through the centre of the earth; but since the moon's effect lessens the earth's rotation, the force does not quite pass through the centre of the earth, but somewhat to one side, so as to pull in an opposite direction to that of the earth's rotation, and, as will be seen from the figure, is thus slackening the speed of the earth's rotation. The total force of the earth on the moon may be decomposed into two forces as in this figure. One of these forces acts through the earth's centre, and keeps the moon in its path, the other force at right angles to this is a tangent to the moon's orbit. It is this latter force which tends to drive the moon farther and farther from the earth. The action of this force is slow, but constant, and is quite sufficient to account for the gradual increase in the moon's orbit.

The month has gone on increasing until it is now a little over twenty-seven days. The increase of the month over the day went on until the month reached its maximum ratio to the day. At this time the month was about twenty-nine days. It must be kept in mind that the days were then not so long as they are present; for though the epoch at which the month assumed its maximum ratio to the day is in the history of the earth-moon system spoken of as recent, yet if measured by our historical standards, it would seem to make the most remote events in history, in comparison, as events of the most recent occurrence.

Our month in comparison with the maximum period consists of two days less than it did, and the ratio of

the month to the day will go on diminishing until the final critical period when it will be unity. The day and the month will then again be equal. Starting from the epoch when the day and the month were equal, each being perhaps a little less than four hours in length, we trace the tidal evolution of the earth-moon system, until the month has assumed the maximum ratio to the day. This period, when the month contained twenty-nine days, may be considered the period when the progress of tidal evolution was half-way advanced. This of course is only speaking from a physical point of view, and not in the sense of measurement by years; for the time that must yet elapse before the epoch of the next critical state of the earth-moon history must greatly exceed the time that has already passed since the first critical epoch when the earth and the moon were close together. It may very naturally be asked, how can any one know that the interval between the first critical period when the month and the day were equal, and that when the month was twenty-nine times as long as the day, was shorter than the period that must elapse before the month and the day are again equal?

The answer is, that during an immense period the earth caused tides on the moon as well as the moon tides on the earth.

The tides on the moon's surface slackened the rotation of the moon, while the lunar tides at the same time slackened the rotation of the earth. The moment of momentum being constant throughout was only kept so by the retreat of the moon. The earth-produced tides on the moon, and the lunar tides on the earth were then acting in concert and driving the moon much more rapidly away from the earth than the lunar tides could alone accomplish. This went on until the action of the earth-produced tides on the moon, compelled it to turn the same face always towards the earth. After this period there could be no longer any tides on the moon's surface, unless

the time of the moon's rotation differed from that of its revolution round the earth. The earth would again in this case produce tides on the moon, and these tides would eventually compel the moon to turn the same face to the earth as before; there in fact would be no rest for the moon until this condition was arrived at. So long as water or molten material existed in the moon the adjustment would be kept up, and the moon just as at present could no longer yield up any energy to the earth-moon system. Even now should the moon's period of rotation on its axis and revolution round the earth not coincide, there could be no tides on the moon's surface; for the moon is now devoid of seas and probably of all molten material. During, therefore, part of the first period of tidal evolution both lunar tides and the earth-produced tides were in action. Another reason why the second period, from the time of the greatest ratio between the length of the month and the day to the second critical epoch, will be enormously longer is, that during the first period the moon was much nearer to the earth than it will be during the second. For this reason the lunar tides were much greater and therefore more effective in slackening the rotation of the earth. The increasing distance of the moon is diminishing the force of the lunar tides, and the process of slackening the earth's rotation is becoming in consequence considerably slower. When the day and the month are again equal each will occupy one thousand four hundred of our ordinary hours! The moon will then be at a great distance from the earth, and the earth will then always turn the same face to the moon. There can then be no longer any tides on the earth, for the water attracted by the moon would, as far as the moon is concerned, remain quite still. This is the condition of maximum stability in the earth-moon system, and might as far as concerns the earth and moon last for ever.

This is a most wonderful result of tidal evolution, and from which there is no escape, unless long before that period the waters of the earth like those of the moon dis-

appear. Of that there is little probability. When the lunar tides have ceased, the solar tides will continue and the rotation of the earth will keep on slackening until the earth is compelled always to turn the same face to the sun and the day becomes a year in length.[1] The day will then be longer than the month. Professor Asaph Hall at Washington in 1877 discovered two satellites revolving round the planet Mars. The time needed by Mars to rotate round his axis is about twenty-four and a half hours; and the smaller and inner satellite of Mars requires only seven hours and thirty-nine minutes to revolve round the planet. That is, it nearly makes three revolutions in one day. Tidal evolution therefore is further advanced in Mars than on our earth. Before Professor Hall's discovery there was no analogous case to that which tidal evolution will bring about on our earth. This is only the barest outline, but may induce some to study this fascinating subject still further. The theory of tidal evolution is due to Professor G. H. Darwin of Cambridge, and those who wish to pursue the subject further should study Professor Darwin's *Memoirs on Tidal Evolution,* and Sir Robert S. Ball's *Time and Tide.*

Tidal evolution does not seem to be able to account for the position of the planets in regard to the sun. It has been stated that the rotational moment of momentum of the moon, owing to the action of the tides, was transferred into revolutional or orbital moment of momentum as long as the moon's period of rotation differed from that of its revolution. The moon must have acquired the position it now has of keeping the same face to the earth long before it was nearly so far distant as at present. For suppose that the moon did not now bend the same face to the earth, and suppose further, that it had still some liquid on its surface susceptible to tidal impression, we know that, owing

[1] The dynamical principles become here too complex; but it is certain that the action of the solar tides will cause the day to become *longer* than the month.

to the smallness of its mass in comparison with that of the earth, as well as owing to the greater tides produced by the earth on its surface, about nine-tenths of the total moment of momentum required for the enlargement of the moon's orbit would have been abstracted from the moon.

This could not have happened unless the moon had rotated at a velocity which would have shattered it to pieces.

To take the case of Jupiter and the sun, it is known that Jupiter does not turn the same face towards the sun. The time of Jupiter's axial rotation is only 9 hours, $55\frac{1}{3}$ minutes. His distance from the sun is 483·3 millions of miles. By Kepler's third law we can easily find the period of his revolution round the sun. Since the Earth is 92·9 millions distant from the sun, it follows that Jupiter is nearly five times as far distant. Now, using Kepler's law, it will be found that Jupiter requires more than eleven of our years to revolve round the sun. His periodic time is 11·8618 of our years. It is thus seen that Jupiter's periods of rotation and revolution are very far from equal. It is further to be stated that Jupiter never has turned the same face to the sun except during the period that he formed part of the nebula from which the planet originated. No doubt there are tides on Jupiter's surface, as he is still a hot body. The point to notice is this, that if the tides caused Jupiter to retreat from the sun, the transfer of the moment of momentum must be abstracted from Jupiter's rotational moment of momentum and given to his orbital. Had Jupiter's period of rotation round his axis been now equal to that of his revolution round the sun, it would not have been possible to assert that his distance from the sun was not due to tidal evolution. Jupiter's revolutional moment of momentum is about thirty times as great as the sun's present rotational moment of momentum. Had the sun possessed a greatly larger volume and much more rapid velocity, and had Jupiter constantly bent the same face to the sun, there would have been nothing impossible in

the fact that Jupiter was produced from the sun in the same manner as the moon was from the earth. The theory of the tidal evolution is therefore chiefly applied to planet-moon systems, and the nebular theory still holds the field in explaining the origin of our solar system. It may here be stated that the action of the solar tides is undoubtedly slackening the rotation of Jupiter as well as that of the other planets of the solar system; and, doubtless, Jupiter's satellites are efficient in their action in the same way as our moon. Tidal evolution is not confined to our earth-moon system, and its effects though slow are certain and continuous.

Sir Robert S. Ball has also discussed the more rapid action of the tides in past ages in depositing strata on the earth's surface. As a matter of course when the moon was much nearer the earth, its tide-producing efficiency was much greater than at present. This is an exceedingly interesting aspect of the subject.

It may be here stated that, starting from the present distance of the moon from the earth, and calculating by means of Kepler's third law its period of revolution when at half its present distance and so on, we see that in the course of the contracting month it would overtake the contracting day.

Let us for example take the distance of the moon at half its present distance. Now by Kepler's law $\frac{1^3}{27^2}=\frac{(\frac{1}{2})^3}{T^2}$, hence $T=9\cdot5$ nearly. This will give rather more than a period of nine days and a half. By trying other distances the period can always be found. If the moon is taken in contact with the earth the distance between their centres is five thousand miles.

The moon in this case would be the forty-eighth of its present distance $\frac{1^3}{27^2}=\frac{(\frac{1}{48})^3}{T^2}$ or $\frac{1}{27^2}=\frac{1}{110,592T^2}$

$$\therefore \quad T^2\times 110,592=27^2 \text{ or } T=\frac{27}{333}.$$

Hence T, the time of the moon's revolution round the earth, was, when the earth and moon were in contact, only $\frac{27}{335}$ of a day, or somewhat less a period than two hours. The time could never have been so short as this. It is, however, proved by this that in the course of its contracting duration the month would overtake the contracting day.

The theory of tidal evolution is thus seen to be fraught with romance, and the ripple of the tides has thus acquired a meaning which remained unknown until its language was understood. It may occur to some reader of this short account of tidal evolution that since there can no longer be any tide on the moon's surface, it will, in the course of ages, cease to bend the same face towards the earth. As the moon retreats farther from the earth, its orbit becomes enlarged, and the period of its revolution round the earth is increased, both owing to the enlargement of its orbit and the diminution of its volocity. With reference to this the writer has received a communication from Sir Robert S. Ball, in which he says: 'The subject you mention is one that has frequently engaged my attention, and somewhere or other I remember having used words to the effect that the privilege of seeing the other side of the moon, which is withheld from all present astronomers, may in some excessively remote age be granted to their successors. But I cannot feel at all sure about it, because, as you know, no materials are absolutely rigid, and it would be hard to say how small a departure from absolute rigidity in the moon's substance might suffice to preserve that adjustment of its face which has been already brought about by tidal action.'

# ENERGY

# ENERGY

ENERGY is a term with which in its everyday use we are all sufficiently familiar. Though words in common use are not in general so susceptible of exact definition as scientific terms, and might sometimes lose in force if so defined; yet we should probably not be far wrong in speaking of a man of 'energetic character' as one who has the ability to overcome obstacles, or in defining a 'man of great energy' as a person out of whom we can get a good deal of work. This, as we shall presently see, is the sense in which the term Energy is used in Physical Science, where, instead of applying it to an individual, it is used in reference to a body or a material system. Instead of at once defining Energy, the more convenient course will be to give one or two examples which will lead up to its definition. A cannon-ball in rapid motion is said to possess energy, since in virtue of its motion it has the power of overcoming resistance such as is met with in penetrating through iron plates or other hard substances. Imagine a railway carriage running on a horizontal line of railway where there is no friction. It would, if left to itself, and if the rails extended far enough, go on at the same rate for ever. But suppose that in its course it come to rising ground, it will gradually slacken in speed as it mounts up, and after ascending through a certain distance will stop. Now if we consider the circumstances connected with these two cases, we see that the cannon-ball in virtue of its motion has the power of overcoming the resistance it meets with in passing through the iron plates. This power we call Energy.

The ability to penetrate the plates is evidently due to the rapid motion which the ball possesses, since the same ball, if brought up slowly towards a plate, would produce no impression upon it.

The railway carriage ascending an incline is an example of a heavy body raised against the force of gravity. The carriage possesses weight, and on its ascending the hill, it raises its own weight against gravity. This, as we shall presently see, means that work has been done, and the car has done the work in virtue of the motion which it possessed before it began to ascend the hill. This property which a body possesses of overcoming resistance or of doing work is defined as Energy.

The following example will show that in order to possess energy it is not always necessary that the body or system should be in motion, and that, though perfectly quiescent, the system may, under certain circumstances, have the power of doing work, no less than a body in motion.

Suppose a stone or other heavy body to have been raised and lodged on the top of a house. The stone rests in this position without motion, yet not without energy. For if the stone be dropped, it can, by means of a cord and a pulley, be made to raise another weight during its fall. This shows that the stone, when at rest, had the power of doing work, and was not, therefore, without energy.

The work done in raising the stone is done in overcoming the attraction between the earth and the stone, and the energy of the material system consisting of the earth and the stone has thereby been increased.

Having defined energy as the power of doing work, it becomes necessary to have an exact definition of work. On account of gravitation the earth has a tendency to draw towards it all heavy bodies. If we take a pound weight and raise it to a height of one foot from the ground, we become conscious that a certain effort is needed to raise it owing to the resistance offered by the earth's attraction to the rising of the weight. Gravity

being a constant force, any given weight raised a given distance against this force will always imply a definite expenditure of energy or work, and to obtain a numerical expression for the work, we only require to choose the units of weight and length. Taking the former as one pound, and the latter as one foot, a one-pound weight raised vertically one foot against gravity is defined as one unit of work, or the foot-pound. If we raise the pound through two feet we shall do two units of work, through three feet three units, and so on. Similarly 2 lbs. raised through one foot denotes two units of work, and 2 lbs. raised through two feet four units of work. From the foregoing examples it appears that, in order to obtain the work, we multiply the weight by the vertical distance through which it has been raised, and the result gives the work in foot-pounds. Since energy is the power of doing work, the quantity of energy contained in any material system will be measured by the amount of work which the system is capable of doing. A body in motion, as has been pointed out, possesses energy in virtue of its motion; it therefore becomes necessary to inquire what relation exists between its rate of motion and its energy. It might be supposed that if a body moving with a certain speed has a given amount of energy, the energy would be doubled on doubling the velocity. This, however, does not express the true relation which exists between the two things. For, when the speed of the moving body is doubled, it is found that its energy is increased fourfold. This can be best shown in the following manner:—If a body weighing one pound is projected vertically upwards into the air with a given velocity, gravity at once begins to act upon it, thereby reducing its speed, until, when it has reached a certain height, it ceases to rise any higher. We shall suppose that the only two forces acting upon the body are gravity and the force with which it was shot upward, and that we take no account of the resistance it meets with from the air. When the body ceases to rise, it

would, of course, at once begin to descend; but instead of this we shall suppose that when on the point of turning it has been caught and kept motionless at its highest point. Those who are acquainted with the laws of falling bodies know that the relation between the height to which such a body will rise and the velocity of projection is given by the formula $h=\frac{v^2}{2g}$, where $h$ is the height to which the body will rise before stopping, $v$ the velocity with which it was projected, and $g$ the value of gravity equal to 32 feet per second. Suppose that in the first instance the pound weight has been projected with a velocity of 32 feet per second the height $h=\frac{32^2}{2\times 32}=16$ feet. If the velocity be doubled, the height $h=\frac{64^2}{2\times 32}=64$ feet. In the case first supposed, the weight in consequence of its initial velocity has raised itself through a height of 16 feet against gravity, and since it weighs one pound, the work done on itself, according to the rule for calculating work, is $16\times 1=16$ foot-pounds. In the second case the work is $64\times 1=64$ foot-pounds, and since the energy is measured by the work we see that the energy in the second example is four times as great as in the first.

In accordance with this result, it is found that when two cannon-balls of equal mass are moving, the one with twice the velocity of the other, the more quickly moving ball is capable of piercing an iron plate four times as thick as that which the slower one can pass through. In the preceding examples we have shown how to calculate the energy acquired by one pound projected vertically upward, with any given velocity, and from this result we can in every case derive the total energy for a weight greater than this by multiplying the energy due to one pound by the number of pounds.

Having shown that a body in motion has a quantity of energy depending upon its velocity, the next step will be

to inquire under what circumstances a body at rest may also be possessed of energy. Returning to the example where the pound weight was projected upwards with a velocity of 64 feet per second, we supposed it to be lodged at its highest point after it had come to rest, when it was incapable of doing more work in virtue of its motion. In this position, however, though at rest, it possesses the same quantity of energy as it had at the commencement of its upward flight. For if we now connect the weight by means of a string with an equal weight lying on the ground, and pass the string over a pulley, the original pound on descending will, if we neglect friction, raise the other weight to its own height, and thus do as much work as was done upon it by the force of projection. The energy possessed by a body thus elevated above the earth's surface is named *energy of position* or *potential energy* in contradistinction to *energy in action*, or *kinetic energy*, from the Greek *kineo*, I move. The energy in this case is due to the fact that the weight at this height is in a position of advantage with respect to the force of gravity, so that if allowed to fall to the ground it will be able to do work during its descent.

When steam has been passed into a cylinder, and pressed down by a piston, the system possesses a certain amount of energy. This may also be regarded as energy due to position, because a weight placed on the top of the piston when in its lowest position is in a position of advantage with respect to the elastic force of the steam which, if allowed to expand, will do work on the weight.

A reservoir of water situated on the summit of a hill is more valuable than the same body of water at a low level. This is owing to the store of energy which it possesses in virtue of its position; and as the water descends this energy may be turned to good account in driving machinery. If the reservoir is situated at a lower level than the machinery the water becomes useless as a motive power. A cross bow when bent, the main-spring

of a watch coiled up, a labourer primed for work with a sufficient supply of food, are instances where the energy is due to position. The following extract from the late Professor Balfour Stewart's *Treatise on the Conservation of Energy* affords an interesting and apt illustration of *energy* due to *position*:

'It is the fate of all kinds of energy of position to be ultimately converted into energy of motion. The former may be compared to money in a bank or capital, the latter to money which we are in the act of spending; and just as when we have money in a bank we can draw it out whenever we want it, so in the case of energy of position, we can make use of it whenever we please. To see this more clearly, let us compare together a water-mill driven by a head of water and a wind-mill driven by the wind. In the one case we may turn on the water whenever it is most convenient for us, but in the other we must wait until the wind happens to blow. The former has all the independence of a rich man, the latter all the obsequiousness of a poor one. If we pursue the analogy a step further, we shall see that the great capitalist or the man who has acquired a lofty position is respected because he has the disposal of a great quantity of energy, and that whether he be a nobleman, or a sovereign, or a general in command, he is powerful only from having something which enables him to make use of the services of others. When the man of wealth pays a labouring man to work for him, he is in truth converting so much of his energy of position into actual energy, just as a miller lets out a portion of his head of water in order to do some work by its means.'

We have already seen that when a body is projected vertically upwards it possesses kinetic energy[1] in virtue of its motion. As it ascends its velocity and consequently its kinetic energy decreases, but at every point of its

[1] We shall in future for the sake of shortness use the terms *kinetic energy* and *potential energy* to denote respectively energy of motion and energy of position.

ascent it has gained a quantity of potential energy equivalent to the kinetic energy lost, and when the body ceases to rise, the kinetic energy vanishes and the energy becomes wholly potential. In every position of the body the relation expressed by the following equality always holds good:—

Kinetic Energy + Potential Energy = A constant.

When the projected body begins to ascend, its energy is entirely kinetic, because while at the surface of the earth the potential energy of a heavy body is zero. On reaching its highest point the kinetic energy has vanished, and potential energy appears in its place. As the body descends, the energy is again reconverted from potential to kinetic. In positions intermediate between the highest and lowest points the energy consists partly of one kind and partly of the other, and as the body moves from one point to another, a constant transformation of one form of energy into the other is constantly taking place, subject always to the condition that the sum of the two remain constant. An excellent illustration of the transformation here referred to is furnished by the vibrations of a simple pendulum. When the bob is at its highest point it occupies a position of advantage with respect to gravity—in other words, its energy is potential. It now begins to descend under the action of gravity, and during its downward motion the potential energy is gradually changed into kinetic until on reaching the lowest point the energy is entirely of the latter kind. As the bob reascends on the other side of the lowest point kinetic energy is gradually lost and a reconversion into potential takes place. There is thus a transformation and retransformation of energy at every quarter oscillation of the pendulum. The solar system, consisting of the sun and planets, furnishes another illustration of this transformation. In this system there is (1) *kinetic energy*, since all the masses are in motion, and (2) *potential energy*, since the planets are attracted towards the sun from which they are separated by certain distances,

and could thus do work while falling into the sun. We know that the sum of the two energies is constant. If then the planets approach nearer the sun, thereby diminishing their potential energy, we shall find that the velocity with which they move in their orbits round the sun will increase so as to increase the kinetic energy, and thus keep the sum of the two constant. If on the other hand the planets move to a greater distance from the sun so as to increase the potential energy of the system, we shall find that their velocity, and therefore their kinetic energy, is diminished.

The illustrations just given are particular cases of a general principle known as the conservation of energy, which asserts that the whole amount of energy in any system which does not receive energy from without or give it out to external matter is constant.

The same examples serve also to illustrate the experimental fact that, so far as kinetic and potential energy are concerned, the one can be transformed into the other.

Engineers and builders who are engaged in the erection of bridges and other large structures often find it necessary to use some form of machine, such as the inclined plane, or a system of pulleys, in order to raise their materials to the required height. It should be remembered that a machine when so used does not create energy, but that its sole function, as is that of all machines, is to change one form of energy into another more convenient for use. Another fact of very great importance in the theory of energy presents itself to our notice in connection with the use of machines. It is found that a machine does not give back the whole of the work which has been spent upon it, but that a sensible loss of energy is observable owing to the friction which arises in the working of its different parts. This loss of energy is in most cases very considerable, and unless we can track this lost portion of energy into its hidden retreat, our assertion that the sum of the kinetic and potential energies is constant would only

be true within very narrow limits, and the statement would not hold good in cases where the motion is resisted by friction. This is not the only case in which there is an apparent destruction of energy. On projecting a body vertically upward, it rises until its velocity is exhausted, and after coming to rest it begins to descend; and if we neglect the resistance of the air, it finally reaches the ground with the same velocity as that with which it was projected. On striking the ground it is reduced to rest. What then becomes of the energy of motion which it possessed? Again, if a cannon-ball in rapid motion strike a target so as to stop its flight, is its energy really destroyed? When a blacksmith hammers a strip of iron on an anvil, what becomes of the energy of the blows which are stopped by the anvil? To all such questions a satisfactory answer must be given before we are entitled to assert that energy is indestructible. It is well known that in cases where energy disappears through friction or concussion, as in the cases above cited, its disappearance is always accompanied by the evolution of heat. By violently rubbing two pieces of wood against each other sufficient heat can be developed to kindle the wood. When the break is applied to the wheels of a railway carriage, a shower of sparks may be observed to issue from between the wheels and the break on a dark evening. When a cannon-ball strikes a target, and its motion is thus suddenly arrested, enough heat is sometimes produced to raise the ball to a red heat. Again, a thin piece of iron placed on an anvil may be considerably heated by a succession of blows from a hammer. It is now known that in all cases of arrested motion, the motion has been converted into heat. It may be asked how is it possible in such circumstances to arrive at the conviction that such a transformation really takes place? The answer is, that when heat has been produced by friction, it is not possible to account for its appearance in any other way except by regarding it as a species of motion. Until the close of the

last century heat had been regarded by natural philosophers as a kind of matter, and as such was considered to be incapable of creation or destruction by any process known to men. When a body gave out heat through friction its capacity for heat was supposed to be diminished by the rubbing, and in consequence of this it parted with some of its heat to neighbouring bodies. If on the other hand it took in additional heat its capacity was supposed to be increased. This explanation came to be regarded as unsatisfactory, and Sir Humphry Davy, about the year 1799, showed that it was untenable. He caused two pieces of ice to rub against one another until they were almost melted by the friction. Ice cannot melt without heat, and he took care to arrange his experiments in such a way that the ice could receive no heat from neighbouring bodies. If heat had been matter the ice could not have been melted by rubbing the pieces together, and to melt them it would have been necessary to provide them with a supply of heat. And since no heat was allowed to reach the ice from the surrounding bodies it must have come from the pieces themselves in the process of rubbing, But to have taken heat from the ice itself would mean that it was still further reduced in temperature, and this would have rendered its liquefaction impossible. Davy's experiment thus shows that heat is not matter, and the only other alternative is to regard it as an invisible motion of the molecules of the ice, into which the motion arrested by the friction has been transformed. Another observer, Count Rumford, had his attention directed to this subject when superintending the boring of cannon at the arsenal of Munich about the year 1798. The limitless supply of heat developed by the action of the borer on the brass casting seemed to him to preclude the possibility of regarding heat as a material substance. In a paper contributed to the Philosophical Transactions for 1798 entitled, *An Inquiry concerning the Source of the Heat which is excited by Friction*, he writes as follows:

'In reasoning on this subject, we must not forget to consider that most remarkable circumstance that the source of the heat generated by friction appeared to be inexhaustible.

'It is hardly necessary to add that anything which any insulated body or system of bodies can continue to furnish without limitation, cannot possibly be a material substance, and it appears to me to be extremely difficult, if not quite impossible, to form any distinct idea of anything capable of being excited and communicated in the manner that heat was excited and communicated in these experiments, except it be motion.'

Another fact not without importance in its bearing upon the question as to the nature of heat is, that if heat is matter, a body to which heat has been added ought to weigh more than the same body before such addition was made, and one from which heat has been subtracted ought to undergo a diminution in weight. No such change in weight is however observable either on the addition or withdrawal of heat from matter.

Assuming that we are to regard heat as motion, the following extract from Professor Balfour Stewart's work on energy, already referred to, will assist the reader in forming a conception as to the kind of motion of which heat may be supposed to consist:—

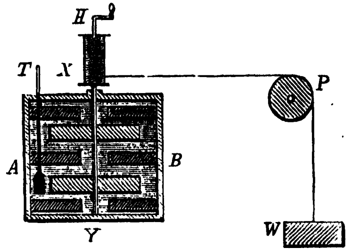
'Imagine a railway carriage full of passengers to be whirling along at a great speed, its occupants quietly at ease, because though they are in rapid motion, they are all moving at the same rate and in the same direction. Now suppose that the train meets with a sudden check, a disaster is the consequence, and the quiet placidity of the occupants of the carriage is instantly at an end. Even if we suppose that the carriage is not broken up and its occupants killed, yet they are all in a violent state of excitement, those fronting the engine are driven with force against their opposite neighbours, and are no doubt as forcibly repelled, each one taking care of himself in

the general scramble. Now we have only to substitute particles for persons in order to obtain an idea of what takes place when percussion is converted into heat. We have or suppose we have in this act the same violent collision of atoms, the same thrusting forward of *A* upon *B*, and the same violence in pushing back on the part of *B*, the same struggle, confusion, and excitement, the only difference being that particles are heated instead of human beings or their tempers.'

So far we have only referred to the general fact that the energy of arrested motion appears as heat. We have yet to explain the method by which the exact numerical relation between a given quantity of energy and heat has been determined. For the precise determination of this very important point, science is indebted to the labours of the late Dr. Joule of Manchester. In order to measure energy in terms of work it was necessary to choose a unit of work. Similarly, to express energy in terms of heat, the energy in question will have to be expressed as so many units of heat, and for this purpose a unit of heat will have to be fixed upon. The heat required to raise 1 lb. of water from 0° (*i.e.* the freezing-point of water) through 1° of temperature on the Centigrade scale is a perfectly definite quantity, and we shall accordingly adopt it as our unit of heat. The object of Dr. Joule's experiments was to ascertain the quantity of mechanical energy equivalent to one unit of heat. For this purpose he caused a known weight to fall through a given height, and the apparatus was so constructed that the weight when falling communicated a rapid rotatory motion to a set of paddles working in a box containing water. The friction of the paddles against the water raised the temperature of the latter, and a comparison between the distance through which the weight had descended and the heat produced in the water enabled Dr. Joule to calculate the relation between the heat and the work.

In order to explain more clearly the principle above

stated, we add a short account of the manner in which the experiments were conducted.




*AB* is a box containing water. A thermometer *T* immersed in the water gave its temperature. The paddles were attached to an axis *HXY*, the upper part of which *HX* could be detached. A string wrapped round *HX* passed over a pulley *P*, and was fastened to a weight *W*, so that as the weight descended the string caused the paddles to rotate with great rapidity. Four stationary vanes were placed inside the box to prevent the water from moving round as a solid mass, and by this means the revolving paddles stirred and agitated the water, thereby raising its temperature. After the weight had fallen through a certain distance which was accurately measured the upper part of the axis was detached, and the weight wound up again without moving the paddles. In this way the accumulated heating effect of several falls of the weight was obtained. This was necessary in order to obtain as much heat in the water as would admit of accurate measurement by the thermometer.

The whole of the potential energy lost by the weight did not go to heat the water. Part was changed into heat through friction at the axis, part also had its equivalent in the kinetic energy acquired by the weight in its descent. Care therefore had to be taken to correct for friction, and by allowing the weight to descend with the paddles detached, Joule was able to calculate how much of the energy of the weight was spent in heating the water. Referring again to the results of the experiment, we have on the one side so many foot-pounds of work expended,

and on the other so many units of heat gained, and the two quantities are equal to one another. The result arrived at by Dr. Joule is as follows:—that 1390 foot-pounds of work are equivalent to the quantity of heat which will raise 1 lb. of water through 1° Centigrade; in other words, one unit of heat if reckoned as energy is measured by 1390 foot-pounds. This shows that if 1 lb. were allowed to fall through 1390 feet and no mechanical work done, but only heat produced, this heat would be able to raise 1 lb. of water through 1° C. This number 1390 is known as the mechanical equivalent of heat. If the Fahrenheit thermometer is used the number becomes 772. This investigation by Joule of the exact connection between heat and mechanical effect was the means of gaining general recognition for the dynamical theory of heat, or that theory which regards heat as motion and not matter. This theory furnishes a simple and satisfactory explanation of many important phenomena, to a few only of which we can refer here. Take, for example, the combustion of a piece of wood or coal. These substances consist largely of the element carbon. The combustion is due to the combination of the atoms of carbon with the oxygen of the air, and the union of the atoms is the result of the action of a force known as chemical affinity. In circumstances favourable for its operation, the atoms of carbon and oxygen rush together, and on coming in contact, the motion of each is suddenly stopped and converted into heat, just as a body falling under the influence of the earth's attraction generates heat by impinging on the ground. To this impact between the countless number of atoms which go to make up a block of wood or a lump of coal and the oxygen of the air, we owe the genesis of all the light and heat which we receive during the combustion of the material. Those who are acquainted with the science of chemistry will readily see that the above example is only a particular case of the general truth that in chemical action the heat of combination is due to the

mechanical action of the force of chemical affinity. In chemical action we have an illustration of the appearance of heat arising out of mechanical action; the phenomena of latent heat furnish us with an example of the converse of this, viz., the disappearance of heat when work has been done. It is well known that when heat is applied to melt ice or to change any other body from the solid to the liquid state, the temperature of the resulting liquid does not rise so long as any portion of the solid remains unmelted. So also, when heat is employed in converting water into steam, the continued application of heat does not raise the temperature of the steam until the whole of the water has been evaporated. The heat in both these instances is supposed to be spent in doing work against the force of cohesion, that is, in pulling asunder the particles of the solid or liquid, and placing them in positions where the mutual force between the particles has been diminished. To understand what is meant by the diminution of mutual force here referred to, we have only to recollect that the attraction of the particles of a liquid on one another is less than the mutual attraction of the particles of a solid, and that in the case of a gas this attraction almost disappears. The heat here spoken of has been called latent because it does not affect the thermometer. It is, however, only hidden and not lost, since it is restored as soon as the water again freezes or the steam condenses.

We have already considered at some length the direct relations between mechanical force and heat. There are many other forms of energy existing in nature; and with respect to all of them it will be found that the two laws of conservation and transformation already referred to hold good. The phenomena included in the different branches of physical science, such as sound, light, electricity, magnetism and chemistry, are all regarded as different forms of energy, and as such are capable of being expressed in terms of heat or mechanical work. Regarded in this light physical science reduces itself to a discussion of the

different forms of energy. Many of the most interesting examples of its transformation occur in connection with electrical and magnetic phenomena, but, except to readers who are acquainted with these sciences, such illustrations, however interesting in themselves, would not be instructive. Those who are desirous of more detailed information on this part of the subject would do well to refer to the writings of Professors Tait and Balfour Stewart.

Having already referred to the fact that energy is capable of assuming a great variety of forms, and also noticed in detail some simple cases of its transformation, the following classified list of energies as given by Professor Balfour Stewart will prove interesting to the reader.

1. *Kinetic Energy, or Energy of Visible Motion.*—Such as we see in the planets, in meteors, in the cannon-ball, in the storm, in the running stream, and in other instances of bodies actually in motion.

2. *Potential Energy, or Visible Energy of Position.*—Such as a stone on the top of a cliff, in a head of water, in a rain-cloud, in a cross-bow bent, in a clock or a watch wound up.

3. *Heat Motion.*—Here we have invisible energy in the form of the motion of the molecules of bodies which we term heat.

4. *Molecular Separation.*—This is analogous to (3), and gives that effect of heat which represents position rather than actual motion. We have examples of this in the case of heat causing bodies to expand, and in the action of heat in changing the state of a body from solid to liquid, or from a liquid to a gas. In both instances energy is stored up, since we see it given back as heat when the body either cools or returns to its original condition.

5. *Atomic or Chemical Separation.*—We have not as yet alluded to this form of energy, and shall illustrate it by reference to the decomposition of water by electricity. Water is composed of two gases, oxygen and hydrogen. One atom of the former is combined with two of the

latter to form what is termed by chemists a molecule of water. In chemical symbols the molecule is represented by $H_2O$.

On passing a current of electricity through the water, the two hydrogen atoms are separated from the atom of oxygen, and the two gases can be collected, each in a separate tube. In these separated atoms there exists a species of potential energy, because, when apart, a strong attraction exists between them, due to the force of chemical affinity, and this force tends to bring the atoms together, just as in the case of a stone raised above the earth's surface, the force of gravitation tends to draw the earth and the stone towards each other. When the two gases are allowed to unite under the influence of this mutual attraction they develop heat, which is the equivalent of the energy expended in separating them.

6. *Electrical Separation.*—When a separation of positive and negative electricities has taken place, a force called electrical attraction, tending to reunite the separated electricities, makes its appearance. There exists therefore a potential energy of separated electricities, since if they are allowed to reunite under the force of electrical attraction work will be done during the combination. This work may either be mechanical, as when an electric discharge is allowed to perforate a glass plate, or it may assume the form of heat and light as in the electric spark.

7. *Electricity in Motion.*—We have an example of this in the current from an electric battery, such as we see developed in a telegraph wire. This current possesses a store of energy, since it is capable either of heating the wire, or of doing useful work in decomposing chemical compounds or in electro-plating.

8. *Radiant Energy.*—The most striking example of this form of energy is the radiation which we receive from the sun in the form of light and heat. This energy on leaving the sun is not instantaneously transferred to us, but before

reaching the earth has to traverse the distance of 92,000,000 miles, the space which lies between the earth and the sun. The time required by light to travel this distance is about eight minutes. Now as we cannot suppose that energy when it leaves the sun ceases to exist as such during its eight minutes' journey, and at the end of that time re-awakens in its old character on reaching the earth, we must regard the radiations, which have left the sun and have not yet reached the earth, as still possessing energy. Energy, moreover, cannot exist except in conjunction with matter; it therefore follows that the matter which transmits light and heat pervades the whole of the visible universe. In a former section reference has been made to the existence of a medium capable of transmitting light from the heavenly bodies to the earth; and we now see that in order to be able to transmit this energy, the medium must be of a material nature, although the matter of which it is composed is quite incapable of affecting the senses.

Under one or other of the foregoing heads reference has been made to most of the forms of energy which exist in nature. If, then, we regard the universe as a whole, the principle of the conservation of energy asserts:—that the sum of all the different varieties remains constant. Energy of motion may be changed into energy of position, into heat, or into electricity; and, again, heat and electricity may be changed back into visible energy; but whatever changes occur, they are only of the nature of transformations, and do not affect the sum-total of the energies.

In considering the different forms of energy, we regard those as useful which are available for the performance of mechanical work. A change of energy from a form in which it is available for mechanical work to a form in which it is not so available, is called the *Dissipation* of energy. It has been pointed out by Sir W. Thomson that though the total quantity of energy remain constant, there is a continual tendency in all kinds of energy to 'run

down' from a more available to a less available form. Dr. Joule, as we have seen, established the law according to which work is changed into heat. Sir W. Thomson, on the other hand, has especially directed his attention to the laws by which heat can be changed into work, and he states that between the two cases there exists this very remarkable difference, that though it is easy in every instance to convert work into heat, there is no known method of reconverting into work the whole of the heat which has been thus produced. In the processes of transformation already noticed, and in all others which actually occur, a certain fraction of the energy is changed into heat. During the swinging of a pendulum a part of its energy of vibration is reduced to that form, owing to friction at the point of suspension and to the resistance it meets with from the air. As it is impossible to recover the heat which has been dissipated in this manner, we must regard this portion of the energy as lost. In the case of a cannon-ball or a meteor moving through the air, the resistance to their motion which these bodies encounter acts like a break in reducing their speed, and transforms a portion of their energy into heat. When a rifle bullet impinges on a target without penetrating it, the whole energy of visible motion will appear as heat. The heat generated in these and similar cases cannot be recovered for any useful purpose. Whenever motion is accompanied with friction a part of the energy of the moving body is degraded into the form of diffused heat. We find an illustration of this in the motions of the bodies which go to form the solar system. Both the diurnal and orbital motions of the earth are, owing to friction, being gradually reduced to the form of heat. Those who are acquainted with the phenomena of the tides are aware that by the action principally of the moon the waters of the ocean are heaped up on the side of the earth facing the moon. The motion of this tidal wave is in the opposite direction to that of the earth's rotation on its axis; and as

the earth revolves, the friction produced by the mutual action between the earth and the liquid protuberance tends to reduce the earth's energy of rotation. In order to put this question to the test, astronomers have referred back to the records of ancient eclipses. Their knowledge of the motions of the sun and moon is now so exact that they can both predict the time when an eclipse will occur and verify the dates of the ancient eclipses referred to in history. By a comparison of the results arrived at by calculation with the facts actually recorded in history regarding ancient total eclipses, astronomers believe that they have detected evidence of a slight diminution of the energy of the earth's rotation. The ultimate effect of this action of the moon on the earth is to reduce its energy of rotation until one revolution of the earth on its axis is performed in the same time as the revolution of the moon on her axis. Under such circumstances there would no longer be any friction between the earth and the liquid protuberance, and consequently no further loss of energy.

In considering the energy of the revolution of the earth in its orbit, we must bear in mind the fact that there is abundant evidence to regard as certain the existence of a material medium pervading the whole of space. It is therefore natural to suppose that such a medium would offer some resistance to the motion of the earth in its orbit round the sun. This supposition is borne out by observations which have been made on one of the smaller comets, called Encke's comet. When it disappears from view the intervals which will elapse before its reappearance are known. Observation shows that these intervals are lengthening, and this points to a decrease in the comet's energy of motion which can only be due to the resistance of the interstellar medium. The same cause, however slow its action, must ultimately affect the motions of all the planets, and gradually convert the mechanical energy of the universe into the form of universally diffused heat, thus rendering it unfit to be the abode of living beings.

Professor Tait, in his *Thermodynamics*, has given an interesting classification of the various forms of energy existing in nature which can be utilised by man for the production of mechanical work, and he has at the same time traced these supplies to their different sources.

Of energy in the potential form he gives the following varieties: (1) Fuel; (2) Food of animals; (3) Ordinary water-power; (4) Tidal water-power; (5) The Energy of chemical separation implied in native iron, native sulphur, etc.

Under kinetic energy, the following are given: (1) Winds and ocean currents; (2) Hot springs and volcanoes.

(1) Fuel consists for the most part of wood and coal. When fuel is burnt it produces large quantities of heat, which man can use either for the sake of warmth, for cooking food, or for the production of mechanical work, such for example as driving engines. If we trace this heat to its source, we shall find that it has been derived originally from the sun. In this we have a case of the transformation of solar energy into the potential energy of chemical affinity. The sun's rays decompose the carbonic acid of the air in presence of the colouring matter of the leaves of plants. The carbon goes to form the wood of plants and the oxygen is set free in the air, ready to recombine with carbon when a fitting opportunity presents itself. In the heat and light given out during the combustion of wood, we have the re-appearance of that portion of the sun's heat which had been spent in separating the carbon of which the wood is composed. Coal has been formed by the action of the sun's rays in the same manner as wood; the energy, however, which it contains has been stored up for many thousands of years, and in burning a piece of coal we are setting free the heat which must have left the sun long ages before.

(2) When we consider food as a source of energy we must look upon it as if it were so much fuel. By its gradual oxidation it maintains the animal heat of the body, and at the same time serves as a source of energy for the

performance of work. The quantity of food consumed by a man varies with the nature of the work which he has to perform. Convicts under sentence of hard labour require a larger supply of food than those who are undergoing simple imprisonment, and a soldier on a campaign requires to be better fed than during a time of peace. Food whether animal or vegetable owes its energy to the sun. In the case of vegetables we have just seen in connection with fuel that they are built up by the action of the sun's rays; and when a man partakes of animal food he may still be said to live on vegetables since the flesh of the animal he consumes has been nourished on grass or some other form of vegetable.

(3) The energy of a head of water is also a result of the action of the sun's rays. By the heat of the sun water is evaporated from the surface of the sea, lakes, and rivers. The vapour is carried by the winds towards the uplands, where it condenses, and becomes when collected as water available for the performance of useful work.

(4) Tidal water-power is capable of affording considerable supplies of useful energy. By the attraction of the sun and moon the water of the ocean is elevated, and if secured at its higher level, it could be made to do work when the tide recedes. This energy, however, is not derived from the sun, but as we have already seen is abstracted from the energy of the earth's rotation on its axis.

(5) Native sulphur, native iron, etc., are forms of energy; since when made to combine with oxygen they are capable of furnishing large supplies of heat. This is regarded by Professor Tait as a primeval form of energy, but as a source of supply for practical use it is of no importance.

Air and water in motion are forms of kinetic energy which can be made of service in doing useful work. The former is largely employed in navigation and in turning wind-mills, and the latter in driving machinery. As regards their source, they are both transformations of

solar energy. For the winds are set in motion by the unequal heating of different portions of the atmosphere by the sun's rays, and running water is the result of the action of gravity in bringing down to a lower level the water which has fallen in the form of rain or snow, but which has first of all been evaporated by the heat of the sun and carried aloft by the winds.

From the foregoing review of the different available forms of energy, it appears that in nearly all cases they are drawn from the sun; and since the earth receives less than the two thousand millionth part of the total energy given out by the sun, we are naturally led to inquire whether his stores of energy are being exhausted, or whether there exists any known means by which he can maintain his heat, and thus keep up a uniform rate of expenditure for an indefinite number of future ages. Before stating the conclusions at which scientific men have arrived in regard to this most important inquiry, it will be necessary to notice briefly the views which have been put forward in regard to the origin of the sun's heat. The most widely accepted theory is that which has been worked out by Sir W. Thomson and Helmholtz. They suppose the matter of which the sun is composed to have been widely scattered in space, and that on being endowed with the power of gravitation the particles of matter gradually came together, and that from the shock of their collision heat has been generated. To understand how such a process could generate heat we have only to remember that motion when arrested appears in the form of heat, and that in the case here supposed the same thing happens as when a stone which has fallen from a height strikes the ground, or when the blow of a hammer has been stopped by an anvil. Though the reader may be willing to admit that heat can be produced by the falling together of the matter of the sun as here described, he may still be inclined to doubt whether this cause is sufficient to account for such enormous quantities of light and heat as the sun has been giving out

for countless ages. It would not be possible in the slight sketch of this theory here attempted to give such details on this subject as the thoughtful reader would wish to have; but it may enable him to feel that he is on firm ground if we state that Sir W. Thomson has calculated that, at the present rate of the sun's expenditure, the energy stored up by the falling together of the matter constituting his mass was sufficient to last for one hundred million years. The hypothesis in question is not only capable of accounting for all the energy possessed by the sun, but it receives additional confirmation from the fact that spectroscopic observations lead to the conclusion that the process of falling together is still going on among nebular masses in regions of space far removed from the solar system.

As the result of the condensation above described the sun initially became possessed of a certain store of energy. A part of this is continually disappearing in the form of radiant heat, and unless he receive some compensating supply we must regard him in the light of a cooling body. As the sun cools the condensation or contraction of his mass still goes on, and by this means a certain amount of heat is liberated which will defray a portion of his expenditure. To see how this happens let us consider the effect of heat on a material body. By the addition of heat a body expands or increases in size. The heat may be regarded as maintaining a certain distance between the particles of the body. If the distance between the particles should from any cause be diminished, or the body contract, less heat will be needed to maintain this new arrangement of particles, the superfluous heat will be set free, and would be called the heat due to contraction. Astronomers and physicists have come to the conclusion that in the heat here referred to as due to the contraction of the sun's mass we have a source capable of defraying a large part of his expenditure. Meteors also by falling into our luminary are supposed to do something towards keeping up his supply of heat. There are, however, various reasons for

supposing that the sun is not contracting fast enough to produce the heat necessary to cover his expenditure, and that in consequence his total energy is decreasing. To show the effect of this on the condition of the sun I again quote from Professor Balfour Stewart: 'If his energy (the sun's) be very sparingly recruited from without, it necessarily follows that he is in the position of a man whose expenditure exceeds his income. He is living upon his capital and is destined to share the fate of all who act in a similar manner. We must therefore contemplate a future period when he will be poorer in energy than he is at present, and a period still further in the future when he will altogether cease to shine.'

When heat becomes generally diffused in the universe there is no longer any energy to be got out of it, for it is only as heat enters or leaves the system that energy is recognisable. If we have a system in which every part is at the same temperature, no work can be obtained from it even if the temperature is high. The high temperature energy of the sun and planets is being gradually reduced to this uniform level through the action of the medium which pervades all space. By the same means their energy of motion is undergoing a gradual conversion into heat, and the effect of this retardation of motion will be that in time all the planets will fall into the sun, whose energy will by this means be for a time recruited. From these considerations scientific men have been forced to the belief that the present order of things cannot be permanent. The following quotation embodies the general conclusions at which they have arrived regarding the probable fate of the universe: 'If this be the fate of the high temperature energy of the universe (the uniform diffusion of its heat) let us think for a moment what will happen to its visible energy. We have spoken already about a medium pervading space, the office of which appears to be to degrade and ultimately extinguish all differential motion, just as it tends to reduce and ultimately equalise all

difference of temperature. Thus the universe would ultimately become an equally heated mass, utterly worthless as far as the production of work is concerned, since such production depends upon difference of temperature. Although therefore in a strictly mechanical sense there is a conservation of energy, yet, as regards usefulness or fitness for living beings, the energy of the universe is in process of deterioration. Universally diffused heat forms what we may call the great waste-heap of the universe, and this is growing larger year by year. At present it does not sensibly obtrude itself, but who knows that the time may not arrive when we shall be practically conscious of its growing bigness? We have here regarded the universe, not as a collection of matter but rather as an energetic agent—in fact as a lamp. Now it has been well pointed out by Thomson, that looked at in this light, the universe is a system that had a beginning and must have an end; for a process of degradation cannot be eternal. If we could view the universe as a candle not lit, then it is perhaps conceivable to regard it as having been always in existence; but if we regard it rather as a candle that has been lit we become absolutely certain that it cannot have been burning from eternity, and that a time will come when it will cease to burn. We are led to look to a beginning in which the particles of matter were in a diffuse chaotic state, but endowed with the power of gravitation, and we are led to look to an end in which the whole universe will be one equally heated inert mass, and from which everything like life or motion or beauty will have utterly gone away.'

# LIGHT

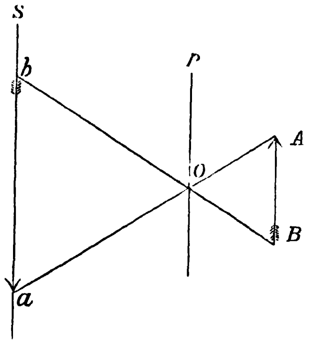
# LIGHT

LIGHT is the external agent which excites in us the sense of sight. Bodies, except such as are self-luminous, are invisible when brought into a dark room, and in order to render them visible the presence of a lighted lamp or candle is necessary. The flame of the lamp or candle is recognised as the seat of an influence which is necessary for vision, and this influence receives the name of light. A self-luminous body, such as a candle or the sun, is the source of an influence which can be exerted at a distance. In this respect the action of a luminous body can be compared to that of one portion of matter acting on another portion at a distance through the attraction of gravity. But though light and gravitation resemble each other in the manner here indicated, there is at the same time a striking contrast in the mode in which the influence is exerted in the two cases. The action of gravitation is not stopped by the interposition of other matter between the two influencing bodies, but in the case of light a very thin screen of opaque matter will arrest its action.

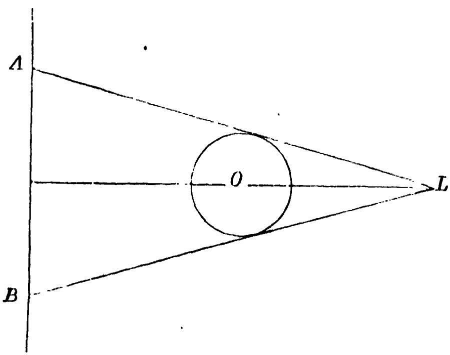
Taking a luminous point as the centre of disturbance it is found that in air or any other homogeneous[1] medium light is propagated in straight lines in all directions round the luminous point. This can be shown by means of two screens, in both of which a small hole has been made. The screens are placed so that both holes are in a line with the flame of a candle. An eye placed against the hole in the screen farthest from the candle will then see the flame. If the candle, the eye, or either of the screens be displaced laterally, the flame will be put out of sight.

[1] A homogeneous medium means a medium of uniform density.

If a small hole be made in the shutter of a dark room, and a white screen be fixed opposite to it, pictures of objects outside the room will be formed on the screen. This can be shown as follows:—Let $S$ be the screen, and $P$ the shutter, with an aperture $O$, $AB$ an external object. Light from the point $A$ of the object will pass from $A$ to $O$, and thence in the same straight line to the screen $S$, forming an image of $A$ at the point $a$. Similarly light from $B$ will form an image of $B$ at the point $b$. Light from the various points of $AB$ lying between $A$ and $B$ will fall on the points of the screen intermediate between $a$ and $b$, and in this way a complete image of $AB$ will be formed on the screen. The direction of the rays shows that the image is inverted.




*Shadows.*—The propagation of light in straight lines explains the existence of shadows. Suppose the source of light to be a luminous point $L$. Light will proceed from $L$ travelling in all directions in straight lines. Let an opaque body $O$ be placed so as to intercept a portion of the rays. If we construct a conical surface with $L$ as its vertex, so as to touch the body $O$ all round, no light will reach the space within this surface to the left of the opaque body.

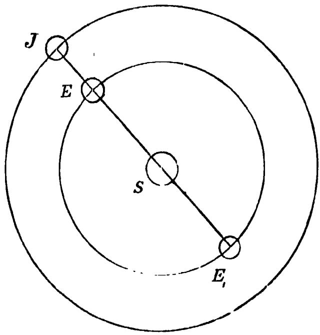


This cone is called the shadow cone, and its intersection with the surface AB will define the shadow on that surface.

The construction above given will afford a general idea of the formation of shadows. When the source of light is not a point but a body of larger dimensions, the formation of its shadow is more complicated. In this case there will be two cones, one of partial shadow and one of total shadow.

*Velocity of Light.*—The velocity of light is so great that ordinary observation fails to afford any indication as to whether light is really propagated in time, or whether it is some influence which depends solely on the condition and position of the influencing and the influenced bodies. If we observe during a thunderstorm at night a tree or other object which has been illuminated by a flash of lightning, the flash and the illumination of the object are, so far as the eye can judge, simultaneous occurrences, though in the one case the light travels straight from the flash to the eye, and in the other from the flash to the tree, and from the tree to the eye. That light is propagated with finite velocity through space was first revealed about 1675 in connection with observations on the eclipses of Jupiter's satellites made by the Danish astronomer Roemer.

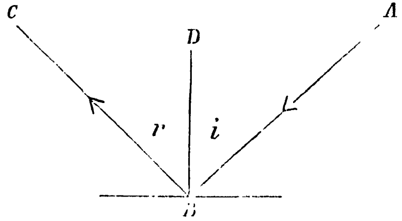
The principle of this method is easily understood. The outer circle in the figure represents the orbit of the planet Jupiter, the inner circle that of the earth, the sun being in the centre. The planet Jupiter is attended by four moons or satellites, which revolve round him at different times. Since light from the sun falls on Jupiter, it will be understood from what has been said respecting shadows that the planet will throw a shadow into space in the direction



turned away from the sun. The first moon performs its revolution in $42\frac{1}{2}$ hours, and at each revolution passes through the shadow, and so undergoes an eclipse. Roemer observed that when the earth was nearest to Jupiter as at *E*, *J*, the eclipses happened earlier than they ought according to the astronomical tables, and when the earth was at its greatest distance from Jupiter, $E_{,}$ $J$, they happened later. Starting from the time when the earth is nearest to Jupiter at $E_{,}$ $J$, the intervals between the successive eclipses are longer than the mean value until the greatest distance has been attained at $E_{,}$ $J$, where the sum of these differences amounted to 16 minutes 26·6 seconds. From this time the intervals are smaller than the mean, and when the earth and Jupiter are again in the relative positions, *E* and *J* (not necessarily in the same part of their orbits), the sum of the decrements amounts to 16 minutes 26·6 seconds. It follows from this that when the earth is nearest to Jupiter, the eclipses are visible 16 minutes 26.6 seconds earlier than when it is furthest away. From these considerations we see that 16 minutes 26·6 seconds is the time required by the light to travel from $E$ to $E_{,}$, the diameter of the earth's orbit, which is about 184,000,000 miles. Light therefore travels $\frac{184000000}{9866} = 186500$ miles per second. It was formerly supposed that a velocity so rapid as this could only be measured by astronomical means; but the experiments of Foucault and Fizeau show that the velocity in question may be accurately determined by terrestrial observations. A description of the methods here referred to, and of several others, will be found in the text-books on Light.

*Reflexion.* When a beam of light *AB*, which has been admitted through a small hole in the shutter of a dark room, falls upon a smooth plane surface at *B*, it proceeds after meeting the surface in a direction *BC*, so as to make the angle *DBC* equal to the angle *ABD*, where *DB* is the perpendicular or normal to the surface at *B*. This pro-

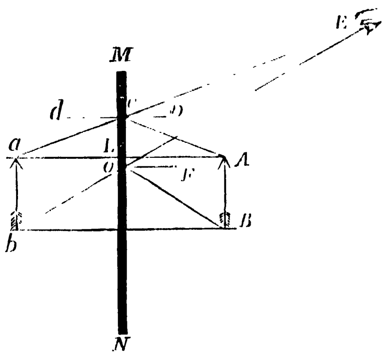
perty of light is known as reflexion, and the angle $ABD$ is called the angle of incidence, and $DBC$ the angle of reflexion. When undergoing reflexion light obeys the two following laws, which are the result of experiment:




1. The incident and reflected rays lie in the same plane.

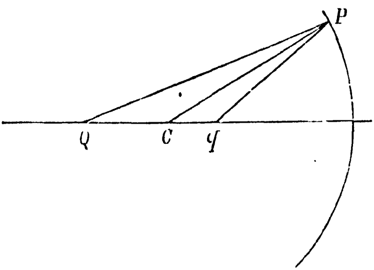
2. The angle of incidence is equal to the angle of reflexion, viz., $ABD = DBC$ in the figure.

*Plane Mirrors.*—Any plane reflecting surface constitutes a plane mirror. Such mirrors produce images behind the mirror exactly similar in form and size to the objects in front of them. This property of mirrors is explained by the laws of reflexion of light. Let $AB$ be an object placed in front of the plane mirror $MN$. Let a ray from $A$ fall upon the mirror at $C$, making an angle $ACD$ with the normal. It will be reflected in the direction $CE$, so that the angle $DCE$ is equal to the angle $ACD$, and an eye situated in the prolongation of the ray $CE$ will see the point $A$ in the direction $EC$, because the image is always seen in the direction in which the ray is travelling where it enters the eye. Similarly a ray from $B$ falling on the mirror at $O$ will be reflected along $OE$, so that the angle $FOE$ is equal to



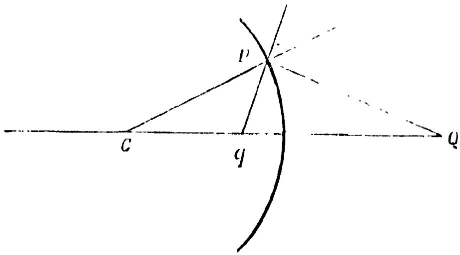
the angle $BOF$. An eye placed at $E$ in the prolongation of $OE$ will see the point $B$ in the direction $EO$. If we draw a perpendicular from $A$ on the mirror, and produce it until it meets the prolongation of the ray $EC$, the point $a$ will become the image of $A$. To find the position of $a$, we have the angle $ACD$ equal to $DCE$ equal to $aCd$ equal to $CaA$, and $ACD$ is equal to $CAa$. Therefore in the two triangles $ACL$ and $CLa$, we have two angles in the one equal to two angles in the other, and the side $CL$ adjacent to one of the equal angles in each triangle common, consequently the side $AL$ is equal to $aL$. This shows that the image of $A$ is at a point $a$ situated at the same distance behind the mirror that $A$ is in front of it. In like manner the image of $B$ is situated at $C$ at the same distance behind the mirror as $B$ is in front. The points which are intermediate between $A$ and $B$ in the object will lie between $a$ and $b$ in the image, so that a complete image of $AB$ will be formed at $ab$ as much behind the mirror as the object $AB$ is in front of it.

If the rays of light proceed from a point $Q$, and fall upon a spherical mirror whose centre is $C$, they will be reflected in a direction $Pq$. In order to find $q$, the point $P$ is joined to the centre $C$ of the mirror. $PC$ is then perpendicular to the



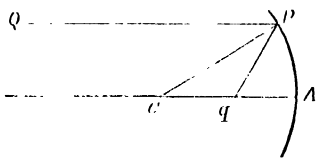

mirror, and by the law of reflexion the angle of incidence $QPC$ is equal to the angle of reflexion $qPC$; and since $PC$ bisects the angle $QPq$, we have (Euc. VI. 3) $QC/qC=QP/qP$. The points $Q$, $q$ are said to be conjugate because they are so related that if a ray of light were to proceed from $q$ in the direction $qP$ it would travel back to $Q$. The relation here found may be expressed by saying—*that the distances*

*of the conjugate points from the centre are to each other as their distances from the reflecting surface.* If the incident ray fall upon the convex surface of the mirror, the proof just given

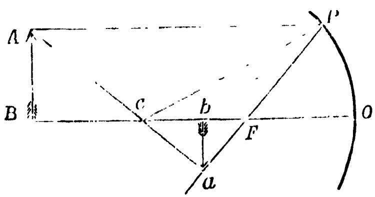



still holds good, since $CP$ bisects the exterior angle of the triangle $QPq$. We have therefore $QC/qC = QP/qP$.

If the incident ray $QP$ be parallel to the radius of the mirror, by the law of reflexion the angle $QPC$ is equal to the angle $qPC$, and the angle $QPC$ is equal to the alternate angle $PCq$, and the triangle $PCq$ is isosceles, and if the mirror is a small part of a spherical surface, $qP$ is nearly equal to $qA$, and therefore $Cq$ and $qA$ are nearly equal, or the radius is bisected in $q$. This point of bisection of the radius is called the *principal focus* of the mirror.



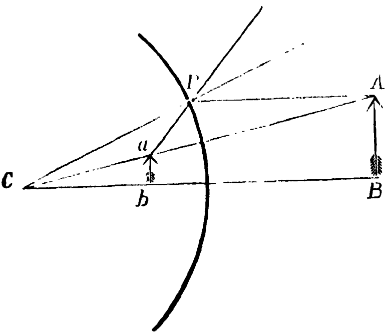

*Images.*—When an object is placed in front of a spherical mirror, every point of the object will send out rays, which after reflexion at the surface will proceed to their conjugate focus, and these taken together will form an image of the object.




Suppose an object $AB$ placed in front of a concave mirror at a distance from the mirror greater than its radius of

curvature. Let a ray *AP* fall on the mirror in a direction parallel to the radius; after reflexion this ray will pass through the principal focus *F*, and when it is produced to meet the line *AC* produced, the point of their intersection *a* will be the conjugate focus of *A*. Here the conjugate focus of *B* will be on *BA* at the point *b*, and the image of *AB* will be *ab*. The relation between the magnitudes of the image and object is obtained from the figure $ab/AB = bc/BC$.

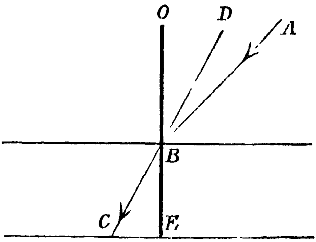
The accompanying figure will show the relative positions of the object and image when the mirror is convex:—




In spherical mirrors, whether concave or convex, both the position and relative size of the image and object vary with the position which the object occupies relative to the centre of the mirror. In some cases the image is erect, in others it is inverted. These different cases are fully explained in all text-books on Light.

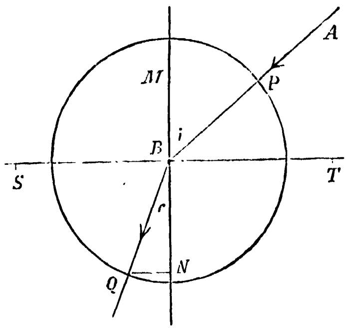
*Refraction.*—When a ray of light passes from one transparent medium to another, it suffers a change of direction at the surface of separation of the two media, so that the direction of its path in the new medium makes an angle with its former direction. This change of direction of the ray is termed *refraction*. As an example, suppose a ray of light *AB* travelling in air to enter a glass plate at *B*. On entering the glass the ray travels

in a direction $BC$, making a smaller angle $CBE$ with the normal to the surface $OB$ than the angle $ABO$, which the former direction of the ray $AB$ makes with the same line. The angle $ABD$, which the new direction $BC$ makes with the original direction $AB$, is found by producing $BC$ backwards.




Suppose, on the other hand, that the ray proceeded from a point $C$ within the glass, and travelling in the direction $CB$, passes at $B$ into the air, its subsequent path would be in the direction $BA$. The principle here explained may be stated as follows. When a ray of light passes from a rarer to a denser medium the refracted ray is bent *towards* the normal, and when the ray passes from a denser to a rarer medium it is bent *away from* the normal.

The laws of refraction like those of reflexion are derived from experiment. Let the line $ST$ represent the surface of separation of two media, say air and water. Let a ray of light $AB$ coming from air enter the water at $B$. The angle $ABM$ which the incident ray makes with the normal $BM$ is called the angle of incidence.

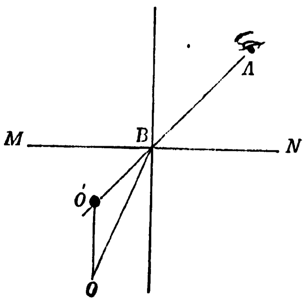



On entering the water the ray is bent towards the normal in the direction $BQ$, and the angle $QBN$, which the refracted ray $BQ$ makes with the normal, is called the angle of refraction. The first law of refraction is:

That the incident and refracted rays are in the same plane.

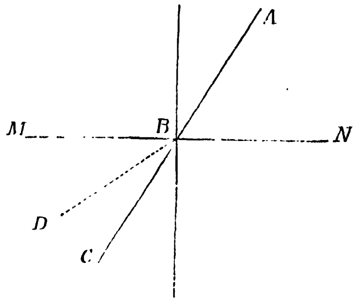
In order to arrive at the statement of the second law, it is necessary to refer to the geometrical construction in the preceding figure. With the point of incidence $B$ as centre describe a circle cutting the incident ray $AB$ in $P$, and the refracted ray in $Q$. From $P$ and $Q$ let fall on $MN$ two perpendiculars $PM$ and $QN$. The law is, that the ratio of the perpendicular $PM$ to $QN$ is constant. This is otherwise expressed by the equivalent statement that the ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant or $Sin\, i/sin\, r = \mu$. The constant quantity represented by this ratio is called the index of refraction. The angle through which a ray is turned out of its original direction by refraction is called the deviation. When the incident ray falls perpendicularly on the surface, it undergoes no deviation, but passes through the second medium in the same direction. The deviation increases with the angle of incidence.

If light come from an object under water, and after passing into the air reach the eye, the bending which the rays undergo at the surface of the water will cause the object to appear nearer to the surface of the water than it really is.



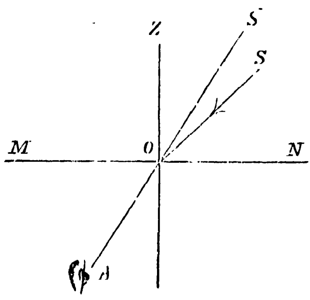

Suppose a ray of light, coming from an object $O$ placed under water, to reach the surface of the water at $B$. On passing into the air, the ray, according to the principle of refraction, will be bent away from the normal, and if we suppose it to enter the eye of an observer at $A$, the object will be seen by him in the direction $AB$, which is the direction in which the ray is travelling when it enters the eye. The object $O$ will accordingly appear to occupy the position $O'$, on the prolongation of $AB$, vertically above $O$, and consequently nearer to the surface of the water.

We may suppose $O$ to be a point at the bottom of a stream or lake containing water sufficiently clear to transmit light, and, from the principle here explained, it is evident that the effect of refraction will be to raise every point at the bottom of the stream towards the surface, and thus delude us into the belief that the water is not so deep as it really is. A straight stick when placed in water in an oblique direction has the appearance of being bent. This is also explained by refraction. When the stick $ABC$ is placed in the water as represented in the figure, the portion $BC$ under the water is seen as if it lay along the dotted line $BD$. The explanation which has just been given of the appearance of bodies under water applies here.




Every point in the portion $BC$ appears to be moved through a certain distance in the direction of the surface of the water, so that to a spectator the outline of the stick will appear to be $ABD$.

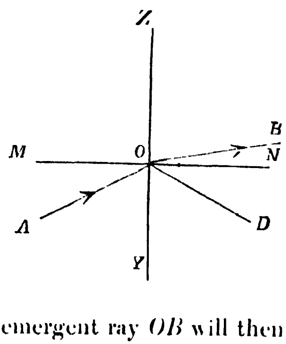
A correction has to be made for refraction in determining the true position of a star. For, unless the star be directly over-head, the light from it undergoes refraction during its passage through the earth's atmosphere, and the observed place of a star will




thus differ from its true place. A ray of light in coming from a star to the earth has first of all to travel through a portion of space destitute of air. On arriving at the earth's

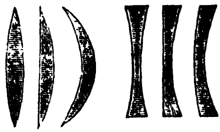
atmosphere, the upper surface of which we shall suppose to be $MN$, the ray encounters a medium of greater density, and on that account is bent towards the normal at $O$. It then travels through the whole thickness of the earth's atmosphere in the direction $OA$ until it reaches a point $A$ at the surface of the earth, where we may suppose it to enter the eye of an observer. And since the star will be seen in the direction in which the ray is travelling when it enters the eye, the observer at $A$ will see the star at $S'$ in the direction of $AO$ produced. The effect of refraction therefore on the position of a star is to bring it nearer to the zenith than it really is. The angle $ZOS'$ is known as the observed zenith distance of a star, and for each observed zenith distance astronomers know the correction which has to be made to obtain the true place of the star $S$.

*Total reflexion.*—Suppose light to be moving from the denser medium below $MN$ towards the rarer medium, starting from the point $A$. Since the ray $AO$ on passing into the rarer medium is bent away from the normal at $O$, the angle $ZOB$ is always greater than the angle $YOA$. It therefore follows that for some value of $YOA$ less than 90°, $ZOB$ will be equal to 90°, and the emergent ray $OB$ will then glance along the surface $ON$. This value of $YOA$ is called the critical angle, and for all values of $YOA$ greater than the critical angle $ZOB$ will be greater than 90°, and the ray $OB$ will never emerge, but will be reflected back into the denser medium. This phenomenon is known as total reflexion.




*Lenses.*—A lens is a transparent body, generally made of glass, bounded by two surfaces, which are portions of spheres. The line which joins the centres of the two

spherical surfaces is called the axis of the lens. There are two classes of lenses, convex and concave. Their forms can easily be understood from the accompanying figures. Convex lenses are known as converging lens because rays of light parallel



to the principal axis after refraction through such lens are made to converge to a point behind the lens, which is called the principal focus. This point $F$ is shown in Fig. 1.

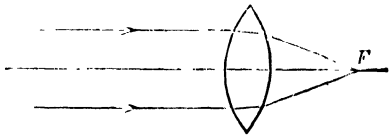



FIG. 1.

Parallel rays incident upon concave lenses are found to diverge after refraction through the lens, and proceed as if they came from a point $F$ in front of the lens. Fig. 2.

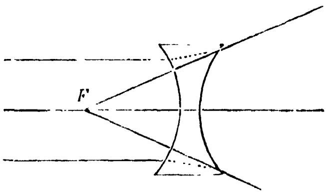
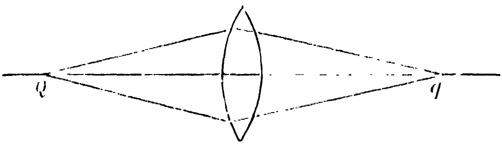



FIG. 2.

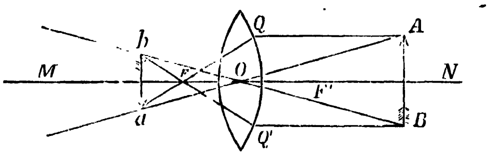
If the rays of incident light are not parallel, but proceed from a point $Q$, the emergent rays converge to a point $q$, which must



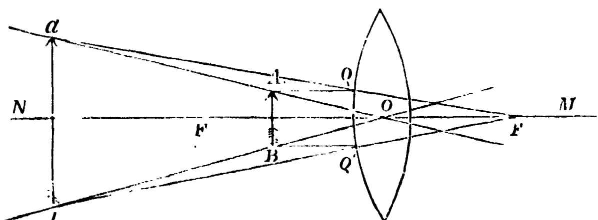

always be so situated that the line joining $Q$ and $q$ passes through the centre of the lens. Conversely, rays proceeding from $q$ would converge to $Q$. Two points which bear this relation to each other are called conjugate foci of the lens.

The formation of images by convex and concave lens

will be understood from the following figures. Let an object $AB$ be placed outside the principal focus $F$ of a convex lens. To find the conjugate focus of the point $A$, join $A$ with the centre of the lens, and let this line be



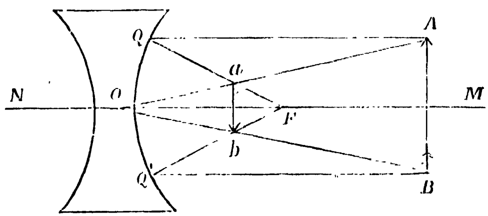

produced to any required distance. Let $AQ$ be a ray of light parallel to the principal axis of the lens $MN$. This ray after refraction through the lens will pass through the principal focus $F$. The point where $QF$ produced meets $AO$ produced determines the position of the conjugate focus of $A$. In the same way the conjugate focus of $B$ will be found by joining $BO$ and producing it as before. Then draw the ray $BQ'$ parallel to $MN$. On passing through the lens this ray will pass through the principal focus $F$. The conjugate focus of $BO$ lies at the point $b$, the intersection of $BO$ and $Q'F$ produced. The conjugate foci of all the points of the object $AB$ make up $ab$, which is the image of $AB$. It is evident from the construction that the image will be inverted, and that its magnitude $ab$ is to the magnitude of the object $AB$ as their distances from the centre of the lens $O$. If the object $AB$ be placed between the lens and the principal focus the position of the image




will be given by following the same method of construction

as in the former case. Let $AB$ be the object placed inside the principal focus. Join $A$ and $B$ with $O$ the centre of the lens. Produce $OA$ and $OB$ backwards. Let $AQ$ and $BQ'$ be two rays parallel to the principal axis $MN$. These two rays after refraction would pass through the principal focus $F$ on the other side of the lens. The points $a$, $b$ where $FQ$ and $FQ'$ produced backwards meet $OA$ and $OB$ produced, will be the conjugate foci of $A$ and $B$, and therefore the image of the two points $A$ and $B$ of the object. The image of all the other points of the object $AB$ will lie in the line joining $ab$, which will accordingly form the image of $AB$. The construction shows that the image is erect, and that its magnitude is to that of the object in the ratio of their distances from the centre of the lens.

If an object $AB$ be placed in front of a concave lens, a construction on the same principle as that for convex lenses will give the position of the image. Join $A$ and $B$ with $O$ the centre of the lens. We have already seen



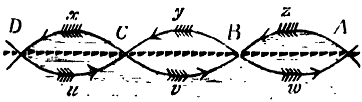

that rays $AQ$, $BQ'$ parallel to the principal axis would emerge from the lens as if they came from a point $F$ in front of the lens. The foci conjugate to $A$ and $B$ will therefore be the points $a$, $b$, at the point of intersection of $AO$, $BO$ with $QF$, $Q'F$. If $ab$ be joined, this line will be the image of $AB$. The image $ab$ is erect, and diminished in the ratio of the distances of $ab$ and $AB$ from the centre of the lens.

Having briefly noticed a few of the more important fundamental properties of light, it will now be necessary

to consider more fully the nature of the agent itself. The sensation of sight is believed to be caused by the vibrations of a medium called the luminiferous ether impinging upon the optic nerve. If light is supposed to consist of vibrations, it is necessary to assume the existence of a medium which will act as the vehicle of transmission of the vibrations. This medium must pervade the whole of space, the interstices between the molecules of all bodies whether solid, liquid, or gaseous; it must in fact exist wherever light is capable of penetrating. Light was formerly regarded as being due to the emission of luminous particles by the influencing body, and the sense of sight was supposed to be due to the impact of these particles on the eye. The two theories are known respectively as the Undulatory or Wave Theory and the Emission Theory. It was found that a very numerous class of phenomena in light were not capable of explanation by the Emission Theory. On this account it has been abandoned, and by means of an experiment, the principle of which is easily understood, Foucault has proved that the theory is incorrect. According to the principle of the Undulatory Theory, light ought to travel slower in a medium such as water than in one of less density such as air. On the other hand, the Emission Theory requires that light should travel faster in the denser medium water than in air. On subjecting these opposite conclusions to the test of experiment Foucault found that the velocity of light is greater in air than in water—a result which, as it is in accordance with the Undulatory Theory, must be regarded as conclusive evidence against the truth of the Emission Theory. The truth of the undulatory theory does not indeed rest solely upon direct demonstration, but those who are acquainted both with the theory and with the complete explanation which it affords of the phenomena of light are irresistibly convinced of its truth.

It will help the reader to form a clearer conception of the vibrations which constitute light if we introduce a few

details in regard to wave-motion. In an undulation the motion is oscillatory, or to and fro like the motion of a pendulum, but no real transference of particles takes place. Each particle vibrates backwards and forwards round its centre, and is capable of communicating a similar power of vibration to neighbouring particles, while there is no transference of matter but a continual transmission of the *form* or *wave*. We have an excellent illustration of wave-motion in the action of the wind on a field of tall grass or corn. We may observe the stalks bend in succession before the wind, each one being set in motion by its neighbour until the wave of bending stalks traverses the whole width of the field. Each separate stalk vibrates round its root as centre, and is thus like an inverted pendulum. The top of the stalks when erect will constitute the crest of a wave and when bent will form the hollow. Now suppose $\lambda$ to be the distance from crest to crest of the successive waves, or as it is called the wave-length, $t$ the time of vibration of each stalk of corn, $v$ the velocity of the wave-motion, or the distance which this motion passes over in one second. This can be obtained by first measuring the width of the field and then observing the time required for one wave to cross it. Since $t$ is the time required by the wave-motion to describe one wave-length, and $v$ its rate, $vt$ must denote the space equal to one wave-length, hence $\lambda = vt$. If we examine the motion of a piece of cork or other light substance floating on the surface of a sheet of water when the waves raised by the wind are coming towards the bank, it will be found that the cork moves forward for a certain distance on the crest of a wave, stops, and then moves backwards though the same distance in the hollow of the next, repeating the same movements as each wave comes up to it. Let $ABCD$ represent the crests of two waves and the intermediate hollows.



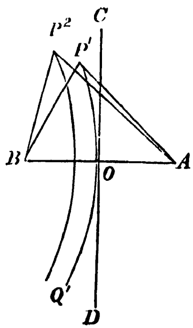
While the whole wave appears to move from the position *AB* to *CD*, the floating cork, and consequently the particles of water only move backwards and forwards through the distance *AB* or *CD*. They move forward on the crest of the wave, and backward in the hollow of the next, as is shown by the arrows in the figure.

The following illustration, though not a case of wave-motion, may assist the reader in conceiving of the transmission of an influence apart from the transference of matter. Suppose a straight and perfectly smooth tube, one thousand miles long, to be filled with smooth shot which fit the tube exactly—we may suppose that six pellets occupy one inch an easy arithmetical calculation will show that no fewer than 380,160,000 pellets are required to fill the tube. Suppose a person at one end of the tube to insert an additional shot, the result of this would be to cause one to drop out at the other end. Now the influence exerted by the operator at one end of the tube must have travelled with more than lightning rapidity from one pellet to the other through its whole length so as to cause one to drop out at the other end in the short space of time which we may suppose a person would require to push a pellet through one-sixth of an inch—this being the distance each individual shot would have to move during the time that the original influence passed over one thousand miles. The waves which cause the sensation of light, as explained in the part which treats of the spectroscope, are of the same nature as those raised on the surface of water by the wind,[1] or such as we see when a stone is dropped on the smooth surface of water. The distance from one crest to another, or from one hollow to another, measures a wave-length. Such waves are named crest and hollow waves, to distinguish them from waves of sound, where the vibrating medium advances and retreats in the same direction as the wave is moving. This

[1] The diagram on page 271 will illustrate the description here given of a wave of light.

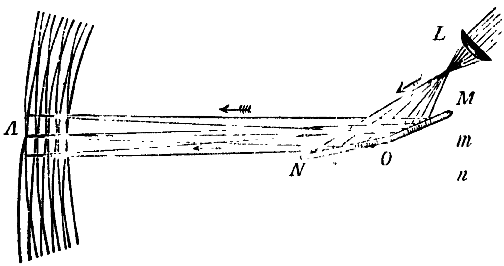
fact is expressed somewhat differently by saying that the direction of vibration of the particles of the medium is at right angles to the direction of the wave motion in the case of the waves of light, whereas in the case of sound waves the direction of vibration of the particles is in the same direction as the motion of the wave.

We shall now explain a property which is characteristic of wave motion generally, and which is of very wide application in explaining many phenomena connected with light. The principle is known as that of interference. It has just been stated that when we drop a stone into still water we have a visible illustration of the progress of an undulation. If we drop two stones into the water at the same time at a short distance from each other, each will give rise to a series of circular waves. The two sets of waves will at first be distinct, but as they proceed the waves from the one centre of disturbance will come into contact with those from the other. Considering each centre of disturbance separately, the displacement produced in each particle of the mass of water by the force proceeding from one centre will be the same in amount as if the other did not exist, and the resultant displacement at any point will be that due to the joint effect of the forces proceeding from both centres. Accordingly, when the crest of a wave advancing from one of the centres coincides with the crest of a wave coming from the other, there will be an elevation of double height, provided the original force of disturbance be the same in the two cases; and when the crest due to one coincides with the hollow of a wave due to the other, there will be neither elevation nor depression, but the water will remain at its ordinary level. The following construction will show the conditions which are necessary for producing the two results here re-



ferred to. Let $A$ and $B$ be two centres of disturbance near to each other on the surface of water. Let $a$ and $b$ denote the distances of any point on the surface from the centres $A$ and $B$. Then, since the distance from one crest to another is the length of one wave, and the distance from a crest to a hollow half a wave-length, it is evident that the waves will reinforce each other, if the difference between $a$ and $b$ be equal to a full wave-length or two half wave-lengths; and generally any two waves will increase each other's effect, or their crests will coincide, if the difference between $a$ and $b$ be an even number of half wave-lengths. Let $\lambda$=wave-length. Then if $a-b=\frac{2\lambda}{2}=\frac{4\lambda}{2}=\frac{6\lambda}{2}=\frac{2n\lambda}{2}$ the crests will coincide. Draw the straight line $CD$ bisecting $AB$ at right angles. Then for all points in $CD$ $a-b=0$. Find a point $P_1$ such that $P_1A-P_1B=a-b=\frac{\lambda}{2}$, then at this point a crest of one wave will coincide with the hollow of another, and the water will be at its ordinary level. If all the points which satisfy this condition be found, the curve which is formed on joining them is known as a hyperbola. If $P_2$ be taken so that $P_2A-P_2B=a-b=\frac{3\lambda}{2}$ another curve of the same nature will be found along which the water remains at its original level, and generally wherever $a-b=\frac{\lambda}{2}=\frac{3\lambda}{2}=\frac{5\lambda}{2}=\frac{(2n+1)\lambda}{2}$ the crest of one set of waves will coincide with the hollow of another and the resulting disturbance is nil. If light consist of undulations of the ether of the same nature as those just described, then two lights of the same refrangibility ought to strengthen each other, if the distances from the source to the place where they mix differ by an even multiple of half the wave-length of that light. On the other hand, when the two lights are of equal intensities, the two disturbances ought to neutralise each

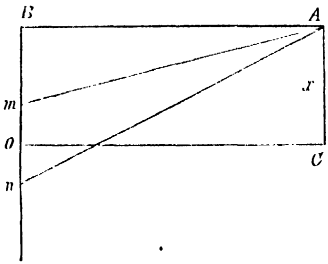
other, or produce darkness, when the difference of the length of their paths is an odd multiple of half a wave-length. It is this production of darkness by the addition of two lights that is known as interference. We shall next describe an experiment which shows that the property of interference *does* really belong to light; and in addition to the confirmation which the possession of this property affords of the truth of the Undulatory Theory, readers will be able to see how by this means the wave-length of the particular light employed may be calculated. The experiment is due to Fresnel, and is a modification of an earlier experiment of Grimaldi. Two plane mirrors *OM* and *ON* are taken. The mirrors may consist of two pieces of plate glass blackened at the back, each mirror being bounded by a straight edge. They are arranged so that the straight edges are close together, and the planes of the mirrors make a very obtuse angle (only a fraction of a degree less than 180°) *MON* with each other. A pencil of red light is admitted




into a dark room, and brought to a point by a lens *L* of short focus. This point is at a distance of a few feet in front of the mirrors, and the light diverging from this falls partly on one mirror and partly on the other. According to the principles of geometrical optics, the light which comes from the focus of the lens will, after reflexion from *OM*, proceed as if it came from *m*, the image of the focus behind the mirror; and the light which falls on *ON*

will appear to come from $n$ the image of the focus formed by that mirror. If the light reflected from the mirrors be received upon a screen, the latter will be seen to be covered with alternate lines of light and darkness. The points $m$ and $n$ are very near to one another, and the existence of the bright and dark lines on the screen shows that the light coming from these points interferes after the manner of waves coming from two contiguous centres or disturbance. If a point $A$ be taken in one of the dark lines, the difference of the distances $Am$ and $An$ will be equal to an odd multiple of half a wave-length, since this is the necessary condition that the addition of two lights should produce darkness.

Suppose $m$ and $n$ to be the two points from which the light proceeds, and let $A$ be taken on any dark line, bisect $mn$ in the point $O$, and draw $OC$ perpendicular to $Bn$ and let $mn=2a$. Let $AC=x$ and $OC=y$, then




$$nB=x+a$$
$$mB=x-a$$
$$nA^2=(Bn)^2+AB^2$$
$$mA^2=(Bm)^2+AB^2$$

$$\text{Therefore } nA^2=(x+a)^2+y^2$$
$$mA^2=(x-a)^2+y^2$$
$$nA^2-mA^2=(x+a)^2-(x-a)^2=x^2+2ax+a^2-x^2+2ax-a^2$$
$$=4ax$$
$$\therefore\ (nA-mA)\,(nA+mA)=4ax. \qquad (1)$$

But since $n$, $m$ are very close together, the line $mn$ is very small as compared with $nA$, $mA$, and therefore each of these lines becomes nearly equal to $OC=y$, therefore $(nA+mA)=2y$. We have already seen that the condition necessary for the crest of one wave to coincide with the hollow of another (or the condition necessary to produce darkness) is $(nA-mA)=(2n+1)\frac{\lambda}{2}$ where $\lambda$=wave-length

of the light employed (in this instance red). Making these substitutions in (1)

$$(2n+1)\frac{\lambda}{2} \times 2y = 4ax$$

$$\therefore\ \lambda = \frac{4ax}{(2n+1)\,y}.$$

The distance $AC$ or $x$ of any dark line from the central line $OC$ can be measured by means of a micrometer, and $y$ the distance of $O$ from the screen can also be measured. Also $x$ is found to be proportional to the odd numbers 1, 3, 5, 7, etc.; hence $x$ will always be proportional to $(2n+1)$ and $\lambda$ will therefore be constant, so long as the refrangibility of the light remains the same. It will be found, however, that $\lambda$ is different for each varying tint of colour; this follows from the fact that the distance $x$ of any dark line from the central line $OC$ varies as the refrangibility of the light varies, or, since the colour of the light varies with the refrangibility, $x$ will have a separate value for every differently coloured ray. Wave-lengths of light are generally stated in terms of a unit of which $10^{10}$ units make one metre. For the rays of mean refrangibility the average value of a wave-length is $\frac{1}{50000}$ of an inch. It has been suggested that the wave-length of some particular kind of light might be adopted as a natural standard to which the fixed standards of length could be referred in case of loss. The British standard of length is the imperial yard, which is defined as the distance between two marks on a metallic bar preserved in the Tower of London, the temperature being 60° Fahr. This distance has been compared with the length of a seconds pendulum. The metre, which is the French standard, is a certain fraction of a quadrant of a meridian of the earth. If the earth is slowly contracting through cooling, this will cause the seconds pendulum to vary in length, since its length depends on the force of gravity, which varies with the dimensions of the earth. The length of the metre would then no longer be comparable with a

terrestrial meridian. The wave-length of light of a given refrangibility would, however, remain constant, and if the length of the standards were known in terms of this, their original lengths could always be ascertained if at any time these standards should have been lost.

In order that waves of light may be propagated in the ether, it must possess the properties known as inertia and elasticity. The term Inertia here signifies that a finite time is required to propagate a finite velocity in a finite portion of it. When any portion of the ether has suffered a displacement relative to another portion, a force tending to bring it back to its original condition is called into action. This force is called Elasticity. For the benefit of the reader I quote at full length from Sir G. Stokes's Burnett Lectures the following instructive and suggestive passage regarding the ethereal medium and the propagation of light in it:—

'First, we learn to regard the interplanetary and interstellar spaces as no mere void, or empty space passed through by swift messengers in the shape of particles of light conveying information from distant worlds, but as filled with an ever-present all-pervading substance, in which the ultimate particles of ponderable matter, including those of our own bodies, are continually, as it were, bathed, and yet of which our senses give us no direct cognisance.

'Secondly, that whatever other important offices this ether may fulfil, this one at any rate belongs to it, that it forms the medium of visual communication between ourselves and our fellow-creatures, between ourselves and the various objects around us, between ourselves and distant worlds.

'Thirdly, that this communication is carried on by tremors of some kind propagated through the ether with a velocity so enormous that for all practical purposes of communication on earth it may be deemed instantaneous. In fact, light would travel about seven and a half times round the whole earth in one second. But so rapid are

those tremors that many hundreds of millions of millions take place in one second. Notwithstanding, therefore, the enormous rate of propagation, the lengths of the waves are excessively small, ranging about the $\frac{1}{50000}$ part of an inch.

'Fourthly, we learn that notwithstanding the almost incredible shortness of the time of vibration, a variation in this periodic time is nevertheless recognisable by our senses, and that it is to this cause it is due that the face of nature does not present to us simply light and shade like a photograph, but that we have that endless variety of colours which we enjoy.

'Fifthly, in the plan of an elastic medium conveying small vibrations we have a mechanism of the simplest possible kind, having for result that rays of light from objects all round cross each other's paths in all sorts of ways without any mutual disturbance. When we survey a varied landscape, each visible point in it, however minute, may be regarded as an independent source of light, from which the light proceeds in all directions. True, the objects are not in general self-luminous; they are seen by the light of the sun or of the clouds which they irregularly reflect, but as regards the behaviour of the pencils which proceed from them they are as good as self-luminous. Well, then, from each visible point, however minute, there enters the eye every second a length of light of about 186,000 miles, that is, light which would have travelled that distance had not the eye been there to catch it, this immense length being filled with undulations of length ranging about 50,000 to the inch. And if the landscape be contemplated by a multitude of persons, from each visible point in it that vast length of light, consisting of undulations of such excessive minuteness, enters the eye of each spectator every second of time; aud all these various streams of light, proceeding in all sorts of directions, cross each other's path in all sorts of ways without the slightest mutual disturbance.

'To one previously unacquainted with the subject, these statements seem like the dreams of an enthusiast, or at best the speculations of some wild theorist, and yet there is nothing in what I have stated beyond the sober conclusions of scientific investigation, conclusions supported by an amount of evidence altogether overwhelming. In saying this it is to be remembered that the precise mode of disturbance of the ether has been left an open question.'

*Dispersion.*—In the article on the Spectroscope it is stated that when a beam of white light, coming through a small hole in the shutter of a dark room, is passed through a prism with its edge downwards, the beam is deflected upwards, and at the same time resolved into light of seven different colours. If this light be received upon the screen the image formed is called the Spectrum. The rays which have undergone the greatest deviation are the violet; and beginning with this the order of their occurrence is as follows: violet, indigo, blue, green, yellow, orange, red. This phenomenon is known as the dispersion of light, and, as we shall point out in another chapter, this breaking up of light into its components by means of the prism is owing to the different refrangibility of the rays. The experiment shows that white or ordinary light is composed of different sorts of coloured light. Newton measured the length of each colour on a spectrum which he had obtained by passing white light through a prism of crown glass; and regarding the whole length of the spectrum as made up of three hundred and sixty units, he found the spaces occupied by the different colours to be in the following proportions:—

| Red | Orange | Yellow | Green | Blue | Indigo | Violet |
|---|---|---|---|---|---|---|
| 56 | 27 | 27 | 46 | 48 | 47 | 109 |

If the circumference of a circular disc be marked off into three hundred and sixty parts, and its area divided into sectors in the proportion of the above numbers, and if each sector be coloured with its appropriate prismatic

colour, it will be found that on rapidly whirling the disc on an axis through its centre perpendicular to its plane, the effect of the rapid succession of colours on the eye is to produce an impression of colour sensibly white. We have in this experiment the production of white light by a synthesis of its components. The recomposition of white light can also be effected by taking a prism in all respects similar to that by which the light was first decomposed, and placing the two prisms with their refracting edges in contrary ways. The light which was decomposed by the first prism will on passing through the second be recombined, and a spot of white light will be visible on the screen. Sir David Brewster's explanation of the colours of the spectrum is different from that of Newton. He considers that there are only three primary colours, red, yellow, and blue; and that in light of the same colour the rays possess different degrees of refrangibility as well as of intensity. According to this supposition the solar spectrum is produced by the superposition of the three spectra of red, yellow, and blue, in which the position of maximum intensity is different. In the red spectrum the intensity is near one end, in the yellow spectrum in the middle, and in the blue spectrum near the other end. The tint at any point of the spectrum would thus depend upon the proportions in which the tints of the three original spectra are mixed at the point.

We shall now notice some of the phenomena which depend upon the *absorption* of light. Since it will be necessary in dealing with the absorption of light to refer to rays of different refrangibilities, readers will bear in mind that the term Light may in an extended sense be used to designate the rays which fall upon all parts of the spectrum. In the chapter on the Spectroscope it is stated that the spectrum consists of three parts; (1) the visible portion extending from the red to the violet; (2) the portion beyond the red known as the heat spectrum; (3) the portion beyond the violet called the chemical

spectrum. Beyond both ends of the visible spectrum, therefore, there are radiations which do not affect the eye; but physicists are now agreed that these radiations are of the same physical nature as those which produce vision, and that their only distinguishing characteristic is a difference in refrangibility or in the wave-length of the undulations by which they are produced. When light is absorbed by any body, the energy of the absorbed light reappears in certain effects which are produced in the absorbing body. One of the most common of these effects is that of raising the temperature of the body which has absorbed the light. But since the rays which act most powerfully in increasing the temperature of bodies are the ultra-red rays (those below the red), the effects resulting from this action belong more especially to the subject of heat.

Chemical action is another of the effects of absorption, and on this is founded the practice of photography. The photographic processes now in use are very numerous. One of the best known is the Collodion Process. A glass plate is carefully cleaned by washing with spirits of wine or some other detergent. It is then wiped with a soft rag and polished with a silk handkerchief. A collodion containing soluble iodides and bromides is made to flow over the plate, the excess being drained off. When the collodion has set into a gelatinous condition the plate is immersed in a bath of nitrate of silver. The plate is gradually lowered into this solution until the action between the silver solution and the solvent of the collodion ceases. The plate is now placed in the dark slide ready for exposure in the camera. After exposure in the camera, the plate is taken into a room lighted with yellow light where the developing solution is applied. This may consist of pyrogallic acid mixed with acetic acid. A solution of ferrous sulphate is also largely used for this purpose. On the application of the solution the image gradually appears. This image is known as a negative.

The paper for printing is prepared by a special process. To render it sensitive it is placed in a solution of silver nitrate of ten per cent. strength; and after remaining in this for about three minutes it is hung up to dry, after which it is ready for use. To print the image the paper is put into a printing frame and placed over a negative and exposed to light. The printing goes on until the picture appears somewhat darker than it is finally intended to be. The final process which the photograph has to undergo is the *toning* and *fixing*. For this purpose many processes are now in use. In the early days of photography a bath of gold chloride and hyposulphite of soda was used. The sketch above given is meant to show how a photograph may be taken, and is not intended as a description of the more recent processes.

*Phosphorescence.*—The phenomenon known as phosphorescence is due also to the absorption of light. Certain substances after having been exposed to the action of light appear luminous in the dark, a property on account of which they are said to be phosphorescent. This property is possessed in a high degree by the sulphides of calcium and barium, by the diamond and certain other precious stones. The phenomenon is produced chiefly by the action of the violet and the ultra-violet rays. Fluorescence is a phenomenon of the same nature as phosphorescence. The former term is used if the appearance is observed while the body is under the influence of the incident light, the latter when the effect is observed after the light from the source has been cut off. When a piece of canary glass coloured with oxide ot uranium is held in the violet or ultra-violet portion of the spectrum, a faint nebulous light extends to a depth in the glass of about a quarter of an inch. When the solar spectrum is thrown upon a screen which has been washed with sulphate of quinine, the ultra-violet portion becomes visible by fluorescence. The light in this case is of a bluish colour. Certain other organic substances will produce the same effect. The explanation

of the luminous appearance both in the case of phosphorescence and fluorescence is to be found in the fact that the substance upon which the light falls absorbs some of the more refrangible rays consisting for the most part of the ultra-violet light. These absorbed rays set up an agitation among the ultimate molecules of the body, in consequence of which the surrounding ether is disturbed and light is given out. The light, however, which is emitted is not of the same character as the incident light, but consists of rays of lower refrangibility. The energy of the incident light is exhausted in the process of producing the phenomena. This was proved by Sir John Herschel, who had been led to observe the peculiar blue colour which became visible under certain circumstances when light is passed through a solution of sulphate of quinine. This colour he found proceeded from a stratum of the liquid near the surface, and he found that the light which had produced this effect in one solution was powerless to set up a similar action in a second solution.

The subject of phosphorescence has been carefully studied by M. Edmond Becquerel, and that of fluorescence by Sir G. Stokes. With regard to fluorescence Professor Sir G. Stokes writes: 'Perhaps the most striking feature in this phenomenon is the change of refrangibility of light which takes place in it, as a result of which visible light can be got out of invisible light if such an expression may be allowed: that is, out of radiations which are of the same physical nature as light, but are of higher refrangibility than those which affect the eye; and in the same way light of one kind can be got out of light of another, as in the case for instance of an alcoholic solution of the green colouring matter of leaves, which emits a blood-red light under the influence of the indigo and other rays. Observation shows that this change is always in the direction of a lowering.'

Fluorescence supplies the means of detecting the presence or absence of rays of high refrangibility in any

given spectrum. When the spectrum is thrown upon a fluorescent substance, this substance renders the ultra-violet rays visible if they exist. Accordingly the presence or absence of fluorescence will show whether such rays are or are not present. In this way also the action of different bodies on these rays may be studied, and useful information be thus obtained in regard to the substances examined. The light which is emitted by a fluorescent substance contains rays of a wide range of refrangibility.

*Colour.*—In regard to 'colour,' it is important that the reader should at the outset start with a clear conception as to what colour really is. If he were asked to say whether he regarded sound as a sensation or a substance he would doubtless answer without hesitation 'a sensation.' If he had to answer the same question with regard to colour we doubt whether the same answer would be given with equal readiness, yet colour is a sensation as much as sound and not a material substance. Colour depends primarily upon the fact that when ordinary light is decomposed the rays of different refrangibilities give rise to different sensations of colour. In some cases colour will depend upon the nature of the light which is given out by the source, in others it will be due to modifications which this light has undergone in its passage to the eye, whereby some of the rays have been suppressed and a certain number have been preserved to enter the eye. Bodies which do not allow light to pass through them, or as they are called opaque bodies, are seen by reflected light. Their colour will be that of the light which they reflect. If a body reflects all the rays of the spectrum in an equal degree, the colour of the body will be that which is due to the light which falls upon it. It generally happens that bodies reflect some of the rays in greater proportion than others; their colour is, therefore, that which arises from the mixture of colours which they reflect. A sheet of white paper reflects in equal proportion all the rays which are contained in ordinary light, and in

consequence its colour is white. A piece of red cloth has absorbed all the rays except the red which it reflects; and the colour of the cloth will be that of this reflected red light. The same explanation holds good in regard to the colours of flowers, the verdure of the fields, and the variety of colours seen in dyed dresses. If a coloured flower be placed on the different parts successively of a pure spectrum, it appears brightest at those parts where the colour of the spectrum most nearly coincides with its own. At some parts it will appear comparatively dark, and at others almost black. This shows that the colour of flowers is due to the fact that they absorb certain sorts of light largely, and reflect other sorts. For when the flower is placed on a part of the spectrum where the colour most resembles the colour of the flower as seen in white light, its comparative brightness shows that it is reflecting this light, whereas when it appears dark or black the absence of colour shows that it is absorbing this light and reflecting none to the eye. When light falls upon a leaf, the structure of the leaf gives rise to irregular reflexions and refractions within its substance, and as the light proceeds some of the rays are absorbed and the remainder reflected. When a body absorbs all the light which falls upon it, it appears perfectly black.

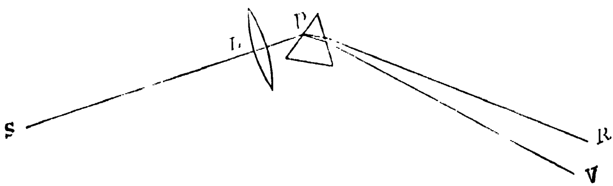
Bodies which allow light to pass through them are said to be transparent. If such a body allow all the rays which fall upon it to pass through, it will appear of the same colour as the incident light, but if it absorb some of the rays its colour will be that due to the mixture of rays which it allows to pass through.

In some cases the colour of a transparent body depends upon the thickness of the matter through which the light has had to pass. This is explained by what is called selective absorption. When the light enters the body certain rays are stopped near the surface, and if the layer of the substance be very thin the remainder will pass through and the body will have the colour of those rays.

But if the light has to traverse a greater thickness of the material the latter will select certain other rays for absorption, and a different mixture of rays will be transmitted, thus causing the body to appear of a different colour. A piece of ordinary red glass transmits red rays, and stops nearly all the others. Green glass on the other hand transmits green and stops red. A combination of these two glasses will accordingly be black, since the light which the red glass allows to pass through will be stopped by the green and *vice versâ*.

When light has passed through two glasses of different colour, its colour is generally such as would occupy a position on the spectrum intermediate between the colours belonging to the two glasses. For example, light which has passed through both a yellow and blue glass will be green; and if light which has passed through a piece of green glass only be analysed by a prism it will be found to consist of green, blue, and yellow. Almost all examples of coloured light are found to be mixtures of several monochromatic lights (lights of one tint). When several different monochromatic lights are received by the eye, all those which fall upon the same spot of the retina combine to form a single resultant colour-sensation, which does not necessarily resemble any of the components. The retina of the eye is composed of a large number of nerve elements, each of which is capable of perceiving one of three primary colours, red, green, and violet. When the elements sensitive to red and to green are simultaneously affected, any colour of the spectrum from red through orange and yellow up to green may be produced. The particular colour will depend upon the relative amount of irritation which has taken place in the two nerve elements. In the same way if green and violet light be mixed in different proportions, different shades of blue will be produced. When all the three sets of nerves are irritated the sensation is that of a simple colour, and by a proper adjustment that colour may be white. There

are several methods by which a mixture of colours may be obtained. One consists in combining reflected and transmitted light. This may be done by looking at one colour through a piece of glass, while the other is seen by reflexion from the surface of the same piece of glass. If sectors of differently coloured papers are fastened on a disc, and the disc be made to rotate rapidly, the colours will blend so as to produce the impression of a single colour, which will be the mean of the colours of the different sectors. Professor Clerk Maxwell's apparatus for obtaining a mixture of colours is both simple in principle and effective in practice. *P* is a prism which, if placed in




the path of a beam of light coming from *S*, would decompose the light and form a spectrum. Again if light from *S* were passed through a lens without the interposition of the prism, the light would after passing through the lens converge to the conjugate focus, and there form an image of *S*. If the light be passed through the lens and afterwards through the prism, it will still converge to the focus of the lens, but since it has been decomposed in its passage through the prism, it will form a spectrum at the focus. Suppose *R* to be a point in the red of this spectrum, and *V* another in the violet. Since *R* is the focus of a red ray which has come from *S*, *S* would be the focus of a ray coming from *R*; or a ray coming from *R* would converge to *S*. Similarly a ray coming from *V* would converge to *S*. In order to study the effect of a mixture of colours by

this arrangement, we may suppose the spectrum to be covered when an observer places his eye at $S$. If now a slit be opened at $R$, the observer will see the lens $L$ filled with red light, and if he had opened a slit at $V$ it would have been filled with violet light. If both slits were opened at the same time, the lens would be seen by a mixture of red and violet; and if another of the intermediate colours, say green, had been exposed, a mixture of these colours would be obtained. Any two colours which when mixed together produce white are said to be complementary. From this it follows that the colour which is complementary to any one of the seven colours of the spectrum is obtained by mixing together in the proper proportion, the other six.

The phenomenon connected with vision, known under the name of accidental images, may be explained here. If a person fix his eyes steadily on a brightly coloured object, and afterwards look at a white sheet of paper, he will see the image of the bright object with its colour changed into the complementary colour. This can be explained in the following way. The particular nerves which have been acted on by the coloured body have become, so to speak, exhausted, and do not respond to the action of the light from the white paper with the same readiness as those which had not been called into action. The complementary colour sensation due to these latter will accordingly preponderate. Other examples of a similar nature might be mentioned. A sheet of white paper placed against a coloured background will sometimes appear to be tinged with the complementary colour of the background. If the object looked at has been very bright, an image of the same colour as the object is sometimes seen. The appearance in this case is due to the persistence of the impression on the retina, and is called a positive accidental image, to distinguish it from that where the colour of the image is complementary to that of the object known as a negative accidental image.

*Colour-blindness.*—It has been already pointed out that there are three distinct colour-sensations (red, green, and violet), which in various combinations produce all our different sensations of colour. Colour-blindness is found to consist in the absence of the sensation due to red. Colour-blindness may then be described as dichroïc vision (the perception of two colours), normal vision being trichroic (perceiving three colours). To the colour-blind the solar spectrum will appear to consist of two distinct colours, with white at their junction, since violet and green with the intermediate blue produce the sensation of white.

By the term Light is generally understood that external agent which excites in us the sensation of vision; but in considering some of its properties we have seen that this is not the only effect which light is capable of producing. As illustrations of its other effects, we have already referred to the elevation of temperature which sometimes results from the absorption of light, to phosphorescence, and to photography. It was also noticed that the radiations concerned in producing a rise of temperature are partly those which fall on the visible spectrum, but more especially the rays falling on the invisible part beyond the red, that phosphorescence and chemical action are caused by the more refrangible rays, chiefly those beyond the violet. We saw also that these different effects are all considered to be due to one and the same agent, so that heat and light are to be regarded as the same physical agent, the former only differing from the latter in the fact that the radiations causing it do not affect the eye, owing to their greater wave-length. It has been proved experimentally that in regard to reflection and refraction, the rays of light and heat obey the same laws. Certain other properties of light which have not been mentioned here are also common to heat. If we regard the visible and the invisible rays of the spectrum as identical in their nature, the phenomenon

of phosphorescence may be looked upon as a species of radiation resembling that which takes place after a body has been heated in the sun's rays. For phosphorescence is a property which certain substances have of appearing luminous in the dark, after they have been exposed to light of the proper kind and intensity. The duration of the effect after the incident light has been withdrawn varies with different substances. It is found that the incident light, or that which gives rise to the phenomenon, is of higher refrangibility than the light which is given out. Now when a body capable of absorbing light has been heated in the rays of the sun, it in turn becomes a source from which radiations are emitted. The rays which are given out are of too low refrangibility to affect the eye, since they fall below the red. It is also found that the capacity of these radiations for passing through or being absorbed by gases, liquids and solids, is different from that of the light which gave rise to the radiation. A little reflection will show that this is exactly the same thing as that which takes place in the case of phosphorescence.

We have already had occasion to notice that with a few insignificant exceptions all the available energy which we possess is due to the sun. This energy is conveyed from the sun to the earth by radiation. We have also seen that the quantity of heat received at the earth's surface can be measured by the sun thermometer. The quantity which reaches the surface of the earth, and which can be measured in this way, is less than the total quantity which falls on the earth including the atmosphere, since a portion is stopped in its passage through the atmosphere. When the quantity of light and heat which falls on a given area of the earth's surface is known, the amount which is given out by an equal area of the sun's surface, and passes into space in a given time, can be obtained by multiplying by the ratio of the surface of a sphere described with the sun as centre, and passing through the earth to the surface

of the sun. Sir William Thomson calculated that the amount of radiation in the form of light and heat which is given out by every square foot of the sun's surface is equivalent to 6000 horse-power.[1] Since the time when this calculation was made, it has been ascertained that sufficient allowance was not made for the absorption of light by the earth's atmosphere, and in consequence of this Sir W. Thomson arrived at a result much below the amount actually given out by the sun. More recent observations made by Professor Langley show that the radiant energy here referred to amounts to about 12,000 horse-power for every square foot of the sun's surface. He made a series of observations, first at the base and afterwards on the summit of Mount Whitney in Southern California, where the air was both clear and dry. The instrument which he used was one of his own invention, called a bolometer. This instrument measures the heating effect of the light which falls on the different parts of the solar spectrum, both visible and invisible. He operated first on a spectrum at the foot of the mountain. He then, as he says, 'ascended many miles into the air meeting the rays on the way down before the sifting process had done its whole work, and there analysed the light all over again, so as to be able to learn the different proportions in which the different rays had been absorbed, and by studying the action on each separate ray to prove the state of things which must have existed before this sifting—this selective absorption—began.' The separate rays which had been measured below were all found to be stronger high up. As the result of his observations, he says that he deduces a new value of the solar heat, his result being, as already stated, 12,000 horse-power per square foot. This shows that the loss of light and heat caused by the atmosphere is nearly double what it was formerly supposed to be. He also writes:—

'We have found it probable that the human race owes

[1] A horse-power is 33,000 foot-pounds per minute.

its existence and preservation even more to the heat-storing action of the atmosphere than has been believed.

'The direct determination of the effect of water-vapour did not come within our scope; but that the importance of the blanketing action of our atmospheric constituents has been in no way overstated may be inferred when I add that we have found by our experiments that if the planet (our earth) were allowed to radiate freely into space, without any protecting veil, its sunlit surface would probably fall even in the tropics below the temperature of freezing mercury.'

At the distance of the earth the amount of energy represented by this solar radiation is one horse-power to every twenty-five square feet. It has been already noticed that the whole system of winds in our atmosphere has its origin in solar radiation. When the earth is warmed by the rays of the sun, it in its turn radiates back to the air the rays of lower refrangibility. The heat thus communicated to it, together with the rays which it absorbs directly, gives rise to the system of atmospheric currents, which has been already described. A portion of the light and heat radiated by the sun disappears in the evaporation of water on the surface of the earth. The vapour, on condensing, falls again as rain, a part of which is needed for fertilising the fields, the rest collects in streams and rivers, from which a constant supply may be obtained for the use of men and animals. The presence of light is necessary for the growth of plants; and since animals and ultimately man depend upon plants for their supply of food, light may be said to play a very important part in the production of food. Plants derive their supply of carbon from the carbonic acid contained in the air.[1] The rays of the sun—chiefly those which are more refrangible—decompose the carbonic acid of the air in presence of the green

[1] The air contains about ·03 per cent. of carbonic acid. This is a compound of carbon and oxygen, and in chemical symbols it is represented by $CO^2$.

colouring matter of the leaves of plants. The plants absorb the carbon, and the oxygen is set free in the air. This action, however, can only take place under the influence of light. This fact may be put to the test of experiment in the following way: Take a few fresh green leaves, and put them in a clear glass vessel filled with water containing a small quantity of carbonic acid in solution. This jar is then placed mouth downwards in a vessel containing water. When the whole is placed in the sunshine, it will be observed that bubbles of gas appear at the surface of the leaves. By-and-bye the bubbles become detached, and rise to the top of the jar. When a sufficient quantity has been collected, the gas will be found, on applying the proper test, to be oxygen.

By the process described above, the energy of light is stored up in plants, which become the food of animals, and by their muscular movements, energy is again given out. In using coal as the means of obtaining the motive power necessary for working the machinery required for carrying on the vast commerce and varied manufactures of modern times, we are drawing upon the energy stored up by light in the luxuriant vegetation which flourished on the earth in past ages. This decayed vegetation, buried in the course of the changes which the earth's surface has undergone, and altered by pressure and chemical action, has become the coal-fields which are found in different parts of the world, and which constitute a possession the presence or absence of which may be said to measure the greatness of a nation. The appropriation of carbon by growing plants will only take place if the carbonic acid from which it is derived exists in the air. The necessary supply is kept up by the respiration of men and animals, aided by that which results from combustion. In respiration oxygen is inhaled from the air. This unites in the lungs with the carbon of the blood, and carbonic acid is given out. The carbon is derived from the vegetables which directly or indirectly form the food

of all animals. Plants take in carbon, and reject oxygen, which, passing into the air, maintains the supply necessary for respiration; animals, on the other hand, breathe the oxygen, and give out the carbonic acid required by the plants.

The exact nature of the chemical action by which plants under the influence of light separate oxygen from carbonic acid is not known, but it is believed to be intimately connected with the green colouring matter of the leaves named chlorophyll (*chloros*, green, and *phyllon*, a leaf). This colouring matter is a mixture of three differently coloured substances, one bluish green, another greenish yellow, and a third called xanthophyll (*xanthos*, yellow, and *phyllon*, a leaf). These three constituents can be distinguished from each other by their different absorptive power for light, and their distinctive fluorescent properties. With the exception of the fungi, chlorophyll is found to be present in all plants, although not in every part of every plant. In the white parts of variegated leaves there is no chlorophyll. The colour of the leaf of a red cabbage is due to the presence of a red colouring matter wholly different from chlorophyll, and which obscures the colour due to the chlorophyll. This red colour can be removed, and the leaf is then found to contain chlorophyll. Its presence in all plants leads to the belief that it must be connected with the important function of appropriating carbon and eliminating oxygen. Experiments were made by Dr. Draper and Dr. Gardner in Virginia for the purpose of determining what particular rays of the spectrum were the most efficacious in the decomposition of carbonic acid. Light was admitted into a dark room by reflection, and passed through a prism so as to form a spectrum. The two processes which they wished to study were, in the first place, the effect of the different rays of light in eliminating oxygen and appropriating carbon, and, in the next place, their effect in causing plants which had been allowed to germinate in

the dark to turn green. They found that the green and the yellow rays of the spectrum acted most powerfully in evolving oxygen from green leaves placed in water charged with carbonic acid. The same rays were also the most efficient in causing yellow seedling leaves to turn green. The blue and the violet rays which act most powerfully on photographic preparations were found to be almost wholly inactive in producing the effects under consideration. Since these two effects are produced by the same part of the spectrum, it is considered probable that the formation of the green colouring matter of plants is a result of the process by which oxygen is separated from carbonic acid under the influence of light. The change from green to yellow which leaves undergo before falling from the trees is also believed to be due to the action of light. In Europe, with the exception of the more southern parts, this change takes place in the autumn, and is a phenomenon with which every one is well acquainted; but in India, where the change of foliage on the trees is only the work of a few days, the yellow tints are more liable to escape observation. When the mixture of substances known as chlorophyll is dissolved in alcohol, and the solution exposed to the action of light, the green colour is found to disappear, and not only is this the case, but nothing is left which will show the action either of chlorophyll or its constituents on the spectrum. The action of the light does not consist in changing the green colouring matter of the leaf into yellow, but in causing the disappearance of the green constituents. Chlorophyll, as was stated above, is a mixture the constituents of which can be separated from each other, and by this separation it can be shown that the yellow substance is already present in the leaves. The action of light is the only known means of producing the disappearance of the green colour without the formation of products of decomposition, which can be detected by their action on the spectrum. It is therefore reasonable to conclude that the action in

question is due to the effect of light. To account for the fact that a leaf remains green for the greater part of its existence, it is supposed that under the action of light there is a constant discharge and reformation of green colouring matter, and that the green which is constantly present is not identically the same matter, but that it is a state of chemical combination through which different molecules of matter pass, in changing from the inorganic forms of water, carbonic acid, etc., to the organic constituents of the plants.

# THE SPECTROSCOPE

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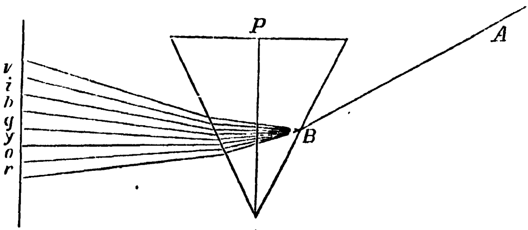
THE discoveries which have been made by means of the spectroscope (Latin *spectrum*, an image, and Greek *skopeo*, I look) already form an important and interesting portion of modern science. This instrument has supplied the chemist with a method of analysis at once delicate and powerful. Quantities of a substance too minute for the application of the ordinary methods are with ease detected by the spectroscope. To analyse a body in the old fashion the chemist requires to possess a sample of it for treatment in his laboratory, whilst by the new method the substances under investigation may lie as far off as the most distant fixed star. The spectroscope can tell us whether the chemical elements with which we are acquainted are confined to the earth or are also constituents of other distant heavenly bodies. The old astronomy explained the motion of the heavenly bodies, and enabled astronomers to determine their weights, while the method of spectrum analysis comes in to supplement and extend this knowledge by enabling them to recognise to some extent the substances of which stars are composed. This method enables us to learn not only what elements are present in the body under examination, but also in what particular physical condition such elements exist. In the case of a star it enables us also to tell whether it is moving towards or away from the earth.

Before proceeding to notice some of the more remarkable revelations for which we are indebted to the spectroscope, it will be necessary to explain shortly the principles of spectrum analysis. Our only means of communication with the sun and stars is by means of the light and heat

which they are constantly radiating into space, and of which our earth receives a portion. This gives us the key to the principle of the spectrum; for if it is to give us any information regarding the sun and stars, it must in some way be closely connected with the light and heat which we receive from them. Before introducing the subject of the spectrum, we shall first describe a few of the properties of light upon which the spectrum depends.

In his treatise on optics Sir Isaac Newton showed that white light—that is, ordinary sunlight—is not homogeneous, but is capable of being broken up into light of seven different tints. If a beam of sunlight, which enters a room through a small opening, be passed through a triangular piece of glass called a prism, the light on passing through the prism is found to be bent from its original direction, and at the same time to be broken up into rays of seven different colours. This is shown in the




accompanying figure, where a ray of ordinary light *AB* falls on the glass prism *P*. On entering this prism the light is broken up into the seven[1] different coloured rays, violet, indigo, blue, green, yellow, orange, red. As it passes through the prism also the light is bent out of its original direction, the direction of bending being in all cases towards the thick portion of the prism. Although the different-coloured rays are all deflected to a certain extent from their original direction *AB*, yet each ray is deflected by a different amount—the red suffering the

[1] The colours are in reality infinite in number, running insensibly into each other. The seven will, however, comprehend the whole.

least amount of deflection, and the violet the greatest. If this light on emerging from the prism be received upon a screen, the band of coloured light so observed is called the *spectrum*.

The rays are arranged in a series according to the degree of their refrangibility, the refrangibility of a ray being said to be greater or less, according as it is more or less deflected from the original direction of the beam *AB*. Thus the red is the least refrangible of the visible rays, and the violet the most. This fact is also capable of being expressed in another way as follows: The more refrangible rays are those of less wave-length, and the less refrangible those of greater wave-length.

Light, as the term is used in common language, is the name for the subjective sensation which we experience when the organs of vision are acted on by a luminous body. The objective cause of this sensation—or light as a subject of scientific investigation—is assumed to consist of the vibrations of an ethereal medium pervading all space and the interstices of all matter. There is sufficient warrant for assuming the existence of this medium in the fact that by this means all the phenomena of light can be satisfactorily explained, which was not the case so long as light was regarded as material particles emitted by a luminous body. Readers who desire to obtain full information in regard to light should consult a special treatise on the subject. For our present purpose it is sufficient to state that the waves or vibrations which constitute light are of the same nature as those which we observe when a stone is dropped on the surface of still water. The distance from crest to crest or from hollow to hollow of one of these undulations measures a wave-length. Ordinary white light consists of an infinite variety of rays all differing in wave-length, and the wave-length of any particular ray determines the position which it will occupy on the spectrum as well as the colour of the light. Confining ourselves to the visible spectrum, the red or least

refrangible rays have the greatest wave-length, the violet or most refrangible the smallest wave-length.

When the light from a body such as a candle is passed through a prism, and the decomposed light received upon a screen the image thus formed is said to be the spectrum of the candle. If the light come from a star the combination of colours presented to us is called the spectrum of the star; and in every case the spectrum derives its name from the particular source from which the light emanated. The instrument used for making observations on the spectra of bodies is named a Spectroscope. It consists of a telescope with a prism in front of the object-glass. The telescope must be so adjusted that the object can be distinctly seen without the prism. The prism being now replaced, the telescope is turned to such an angle that the light which comes from the object shall, after passing through the prism, pass into the telescope. On looking into the latter the spectrum of the body under observation is distinctly seen. The above arrangement, which forms the essential part of a spectroscope, could only be used when the object to be examined is a luminous point, such as a star or planet. In order to make the instrument available for use in all cases, it is usual to place between the substance to be examined and the prism a tube with a narrow slit at one end. A lens is also fitted in the interior of this tube in such a position that the slit occupies its focus. A beam of light entering by the slit will thus, after passing through the lens, emerge as a parallel pencil, and so fall upon the prism, when the spectrum will be formed in the way just described. The radiations which constitute a spectrum consist both of luminous and of heat rays. The existence of the latter is shown by means of the thermopile—an instrument used for the detection of small quantities of heat. The indications of this instrument show that the heating effect decreases as we pass from the red end towards the violet. On the other hand, as we proceed towards

the violet of the spectrum, the light begins to show increased chemical activity. This is inferred from the fact that these rays act more energetically upon sensitised photographic paper. The two characteristics here referred to, which distinguish the opposite extremities of the visible spectrum, lead us to notice the existence of two invisible spectra, so called from the fact that they produce no impression upon the eye.

$r$ $v$

| Heat. | Visible. | Chemical. |
|---|---|---|

In this figure the space from $r$ to $v$ is supposed to include the visible spectrum. The invisible heat spectrum extends to the left of the red, and the heating effect in this space is even greater than it is in the red of the visible part. The invisible chemical spectrum lies to the right of the violet, where it will be found that chemical action takes place more energetically than in the violet. The existence of these two invisible spectra would seem to indicate that only rays of a particular wave-length are capable of affecting the eye so as to produce the sense of vision, and that for this purpose the wave-length of the rays in the chemical spectrum is too short and in the heat spectrum too long. A phenomenon analogous to this may be observed in the case of sound, where the pitch of certain notes is too high and of others too low to affect the ear.

Having described one of the methods by which a spectrum may be obtained, and at the same time passed under review the more general properties of the spectrum itself, we are now prepared to pass on to the consideration of its use as an instrument of research. In the short sketch which we are now giving of this subject, much must be omitted which most readers would desire to know, and for more ample information recourse must be had to a special treatise.

The Spectra of bodies are of three different kinds :—

1. Continuous spectra. 2. Spectra consisting of bright bands or lines on a dark background. 3. Continuous spectra crossed by dark lines.

The two following facts are also in most cases true, though not universally so :—

1. Bodies in the solid and liquid states give a continuous spectrum. 2. The spectrum of gases and vapours consists of bright lines or bands.

With regard to these two statements, it is found that if the light from a candle or from a piece of white hot iron or the electric arc is being examined by the spectroscope, the spectrum is found to be continuous, that is, there is no break in the series of colours from the red to the violet. And in the same way if any metal whatever be raised to a white heat, provided this can be done without vaporising it, the spectrum will be continuous from end to end, and will consequently afford no information in regard to the nature of the substance.

The case stands quite otherwise with the spectrum of gases and vapours. Every different chemical element in the gaseous state, when heated until the gas or vapour becomes luminous, gives a spectrum which is discontinuous, that is, a spectrum consisting only of bright bands or lines on a dark background. The line—or lines where there are more than one—is peculiar to each element, and serves to distinguish it from every other element, since no two of the known chemical elements are found to have identical lines, that is, lines occupying the same position on the spectrum. In these two facts we have the principle of spectrum analysis as applied to chemistry, and it is one of extreme beauty and delicacy. By its means the chemist can detect the presence of an element in quantities which are too minute for the ordinary methods of chemical analysis to deal with. Sir Henry Roscoe states that a quantity of the metal sodium so infinitely small as the $\frac{1}{180,000,000}$ part of a grain can by this method easily be detected. The spec-

trum has also led to the discovery of several new elements which, but for the extreme delicacy of this test, would probably never have been known. A little reflection will show how a new element will unmistakably proclaim its existence if present in the light which happens to be under examination in the spectroscope. When the spectrum of all the known chemical elements has once been examined, and the position of the lines belonging to each one of them marked on the spectrum, the appearance of a new line, and one which the observer could not ascribe to any substance hitherto known to him, would at once point to the existence of a new element. This method of discovery cannot fail to be rigorously exact. When the element has once been detected, recourse is had to the ordinary chemical methods to investigate its properties. We see then that a spectrum consisting of bright lines is in all cases a sure index of the particular chemical elements present in the light under examination, and this is true whether the light be of terrestrial origin or proceed from some far-off heavenly body.

We have next to turn our attention to the third kind of spectrum above referred to, viz., that containing the dark lines. The best example of this spectrum is that of the sun. When examined, it is found to contain all the colours from red to violet, but in addition to this it is crossed at right angles to its length by a large number of dark lines. Only the dark lines here require to be attended to; and when once the key to their interpretation is known, it will be seen that they are as sure a guide to a knowledge of the constitution of the sun as we have just seen the bright line spectrum to be in the cases we have been considering.

These dark lines were observed for the first time about the year 1802 by Dr. Wollaston. After him Fraunhofer, a German optician, made a careful examination of the lines, and mapped no fewer than seven hundred and fifty-six of them in the year 1814. Since that time they have been known as

Fraunhofer's lines. The mapping and observation of these lines is of great importance in physical science, because from a knowledge of the exact position of the lines on the spectrum it is possible to learn what metals are present in the sun. They indicate spaces in the spectrum where certain rays of light are wanting. The explanation of their meaning follows from the principle enunciated by Kirchhoff and Bunsen of the University of Heidelberg, *that a glowing gas or vapour absorbs rays of the same refrangibility as those it gives out.* The meaning of this is, that every gas or vapour gives out rays which occupy a certain position on the spectrum, or which in other words are of a certain refrangibility. Now if any other light has to pass through this vapour before reaching the spectroscope, the vapour will absorb the rays of the same refrangibility as those given out by itself, and consequently there will be a dark line on the spectrum where the absorbed light would have fallen had the vapour not been present. The spectrum of the metal sodium consists of one bright double line situated where the yellow occurs in the continuous spectrum. It had been observed that two of Fraunhofer's dark lines, viz., those marked D,[1] coincided with these bright sodium lines: and Kirchhoff wishing to test this asserted coincidence brought a flame coloured by sodium in front of the slit of his spectroscope, so that the sodium spectrum might overlap the solar one which he had already obtained. The dark lines D in the solar spectrum then became bright lines. This showed that the light from the sodium flame supplied what was wanting in the spectrum of the sun, and that from some as yet undiscovered cause the sodium light had been cut out of it. He next exchanged the solar spectrum for a continuous one, that is, one without dark lines, and showed how dark lines could be produced in it. He caused the light producing the continuous spectrum to pass through a flame containing the vapour of sodium, and

[1] The letters of the alphabet are employed to denote particular lines in the spectra of bodies.

immediately dark lines were seen in the spectrum occupying the position of the sodium lines. The inference to be drawn from this experiment is, that the sodium vapour has absorbed the light of the same refrangibility as its own rays. We thus arrive at the principle above stated, *that when light from any source whatever is passed through a gas or vapour, the gas or vapour will absorb those rays only which are of the same refrangibility as the rays of the absorbing gas or vapour, and allow the others to pass through.* Kirchhoff then reasoned as follows: that we can account for the existence of a dark line in the place of the bright sodium line in the solar spectrum, if we are to suppose that sodium vapour is present in the sun's atmosphere; and that as the light coming from the solid or liquid body of the sun passes through this vapour, the light of the same refrangibility as that which the vapour gives out is absorbed, and a vacant space or dark line appears in the solar spectrum. If sodium vapour be present in the atmosphere of the sun, the inference is that sodium is one of the elements in the sun. In the same way all the other dark lines indicate the presence of vapours which have absorbed the light which would otherwise have fallen on those spaces. In order to learn what elements are represented by these lines we have only to remember that the position of the bright spectrum lines peculiar to the various chemical elements is known, and that the presence of a dark line in the place of any of those bright lines shows us that that particular vapour must be present in the sun's atmosphere, and therefore also in the sun itself. In this way it has been ascertained that many of the known terrestrial elements are present in the sun. Kirchhoff found—in addition to sodium already mentioned—iron, calcium, magnesium, chromium, nickel, barium, copper, zinc. Ångström and Thalen swelled this list by discovering the presence of hydrogen, manganese, aluminium, and titanium. Other no less interesting discoveries made by means of the spectroscope relate to phenomena visible during total

eclipses of the sun. A total eclipse of the sun occurs when the moon passes between the earth and the sun in such a manner as to hide the entire face of the sun from observers situated at certain points of the earth's surface. On the occurrence of one of these eclipses, as soon as the sun's light is wholly cut off by the advancing moon rose-coloured tongues of flame named *protuberances* are seen to shoot up from the surface of the sun to a height of 80,000 or 90,000 miles. Before the spectroscope had come into use, these red protuberances were generally regarded as clouds floating in the atmosphere of the sun. The discovery of the true nature of the matter of which they consist was made independently by Mr. Norman Lockyer in England, and M. Janssen, a French astronomer. The latter had been sent out to India by the French Government to carry out spectroscopic observations in connection with the total solar eclipse of 18th August 1868. For this purpose he selected an elevated position at Guntoor, where the air was remarkably clear and dry. While watching the progress of the eclipse, a large protuberance presented itself at the moment of totality; and on directing the spectroscope to this he found that the spectrum consisted of the bright lines due to glowing hydrogen. During these same months Mr. Norman Lockyer had been conducting experiments in England, based on the idea which had occurred to him two years before, that the protuberances could be observed under the ordinary conditions of the sun's disc, that is, without the intervention of a solar eclipse. The method by which Mr. Lockyer realised this idea is described by him in the *Proceedings of the Royal Society*, xvii. p. 131. In this paper he states that under proper instrumental and atmospheric conditions the spectrum of the protuberances is always visible. This spectrum he found to consist of three bright lines, of which two belonged to hydrogen. M. Janssen, while conducting his observations in India, had also independently of Mr. Lockyer succeeded in observing the spectrum of the pro-

tuberances when the sun was un-eclipsed. Mr. Lockyer's discovery was communicated to the Royal Society, and that of M. Janssen to the French Academy nearly at the same time; and it is not a little remarkable that such an important discovery should have been made simultaneously by two men who were working entirely independent of each other. After this discovery Lockyer extended his researches, and gave it as his opinion that the protuberances were elevated portions of a continuous layer of hydrogen gas surrounding the whole surface of the sun. This layer or atmosphere was named by him the *chromosphere.* The protuberances are supposed to be the result of storms due to local changes of temperature in the chromosphere, and Sir Henry Roscoe observes that the startling rapidity with which these huge masses of hydrogen appear and disappear proves that these hurricanes are of constant occurrence in that region. The following extract from Professor Newcomb's *Astronomy* will convey to the reader's mind a vivid picture of the fierce war of elements, and of the gigantic scale on which natural operations are carried on in connection with our luminary :—

'If we call the chromosphere an ocean of fire, we must remember that it is an ocean hotter than the fiercest furnace, and as deep as the Altantic is broad. If we call its movements hurricanes, we must remember that our hurricanes blow only about a hundred miles an hour, while those of the chromosphere blow as far in a second. They are such hurricanes as coming down upon us from the north would in thirty seconds after they had crossed the St. Lawrence be in the Gulf of Mexico, carrying with them the whole surface of the continent in a mass, not simply of ruin, but of glowing vapour, in which the vapours arising from the dissolution of the materials composing the cities of Boston, New York, and Chicago would be mixed in a single and indistinguishable cloud. When we speak of eruptions, we call to mind Vesuvius burying the surrounding cities in lava; but the solar eruptions, thrown

fifty thousand miles high, would engulf the whole earth, and dissolve every organised being on its surface in a moment. When the mediæval poets sang

> "Dies irae, dies illa
> Solvet saeclum in favilla," [1]

they gave rein to their wildest imagination without reaching any conception of the magnitude or fierceness of the flames round the sun.'

Another interesting appendage of the sun, which only becomes visible during a total eclipse, is the corona. This is the name given to the ring of soft silvery light which surrounds the moon during the occurrence of a total solar eclipse. Much careful study has in recent years been applied to the spectrum of the corona, but as it can only be satisfactorily examined during the brief moments of a total eclipse, intervals of time more or less long must necessarily elapse before the data can be obtained which are necessary for forming definite conclusions regarding the nature of the material composing the corona. Observations made during two eclipses, which occurred in 1869 and 1870, showed a faint continuous spectrum crossed by a single bright green line, which has not been identified as belonging to any known terrestrial substance. Janssen found that the continuous spectrum contains some of the dark Fraunhofer lines, which proves that a part of the light with which the corona shines is reflected sunlight. This can be explained by supposing that meteoric matter, either circulating round the sun or falling into it, is present in sufficient quantity to reflect the sunlight from the corona and thus give the continuous spectrum with the dark lines. In 1882 photographs of this spectrum were taken in Egypt which showed the existence of many new lines.

When the face of the sun is carefully examined by the

[1] Translation.—'The day of wrath, that day shall reduce the things of time to ashes.' Beautifully rendered by Sir W. Scott—

> 'That day of wrath, that dreadful day,
> When heaven and earth shall pass away.'

telescope, it will be observed that his brilliant surface is usually marked with dark spots. When the image of a sun-spot is examined by the spectroscope, the spectrum is found to be crossed by dark bands. These bands show that within the spot a general absorption of all the rays is taking place, and that consequently the temperature of a sun-spot is lower than that of the solar surface round the spot. In addition to the dark spots, bright stripes named faculæ are generally visible on the surface of the sun. The faculæ are accompanied by the incandescent vapours of several well-known metals, such as sodium, iron, and magnesium. These vapours are thrown up from the lower to the higher regions of the sun's atmosphere. It has been supposed that there is a connection between a sun-spot period and certain terrestrial phenomena. Sir W. Herschel collected statistics to show the connection between the number of sun-spots and the price of corn. His theory was that when there were few spots prices were low, and when they were more numerous prices rose, and that the fewer the spots the more favourable the sun's rays were for the growth of corn. Sir W. Hunter also compiled statistics showing a connection between periods of maximum sun-spots and famines in India. Subsequent observations, however, do not appear to have confirmed these observations. It seems, nevertheless, to be established that magnetic disturbances and displays of the aurora borealis are more frequent during the periods when the sun-spots are most numerous.

As we have already said, the field of inquiry opened up by the spectroscope extends beyond the boundaries of the solar system. By the application of this powerful method of research astronomers have been able to carry their investigations into the hitherto unexplored regions of the fixed stars, and to learn something of the chemical and physical condition even of comets and the nebulæ. The names most closely associated with the researches here in question are those of Dr. Huggins, Dr. Miller, and Mr. Norman

Lockyer. In order to carry on spectroscopic observations on the stars, arrangements of a very delicate nature are required. These have to be such that both the light from the star and that from the substance whose presence or absence in the star it is desired to ascertain should fall on the prism together. The rays from the substance must pass through the prism either over or under the beam from the star into the eye-piece, so as to have the spectrum of the substance and of the star side by side. By this arrangement the dark lines in the stellar spectrum can be compared with the bright lines of the substance under examination.

The reader will be able to appreciate more fully the facts which the spectroscope has revealed in connection with the fixed stars, if we first state a few particulars regarding these bodies themselves. When we leave out of account the sun and his small group of attendant planets, the countless other bright bodies which shine over our heads every night are known as fixed stars. It is not possible to arrive at any estimate as to their number, since they only reveal themselves in ever-increasing numbers the more powerful and delicate the means of observation employed. As many as 6000 have been counted as visible by the naked eye over the entire hemisphere. With an ordinary binocular this number can be raised to 120,000, and the number of stars which can be seen with the most powerful telescopes exceeds the population of the North West Provinces of India. In addition to those which become visible by the aid of these powerful telescopes, photography reveals to us the existence of other stars so distant that their light is too feeble to enable them to be seen through a telescope. The faint glimmering of light which they send to the earth is, however, powerful enough to act on a sensitive photographic plate, where the images of the stars are produced each by its own light. This astonishing fact at once suggests to our imagination an endless vista of stars stretching to infinite depths in

space. The results of the spectroscopic researches on the fixed stars are summed up by Dr. Roscoe as follows:—

'The result at which we have arrived is that the constitution of the star-light, although not identical with the light given off by the sun, is yet similar, that is to say, the light of a fixed star gives a continuous spectrum, interspersed by dark shadows or bands, and hence the conclusion we come to is that the physical constitution of the fixed stars is similar to that of our sun, that their light also emanates from intensely white hot matter, and passes through an atmosphere of absorbent vapours—in fact, that the stars are suns of different systems.'

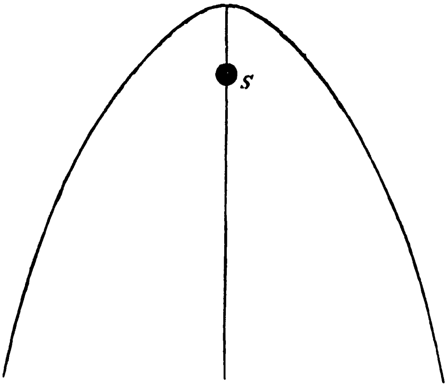
Drs. Huggins and Miller examined the spectrum of the stars Aldebaran and the star in the constellation of Orion. In them they found evidence of no fewer than nine elements, namely, hydrogen, sodium, magnesium, calcium, iron, bismuth, tellurium, antimony, and mercury.

Sir Henry Roscoe continues:—

'We have thus arrived at a distinct understanding of the physical condition of the fixed stars; they consist of a white hot nucleus giving off a continuous spectrum, surrounded by an incandescent atmosphere, containing the absorbent vapours of the particular metals. These results are interesting as bearing on Laplace's nebular theory, because they show that the visible universe is mainly composed of the same elementary constituents, although certain of the stars differ widely from one another in their chemical constitution.'

The true nature of comets is involved in much obscurity. They differ in many respects from planets. The latter are spherical bodies similar to the earth, while comets are irregular in shape and composed of very unsubstantial materials. Planets move in nearly circular orbits, and their movements can be calculated with the utmost precision. The orbits of comets are generally speaking parabolas, and as this is an open curve (see accompanying figure), whose branches extend to an infinite distance, a body

moving along such a curve can never twice trace out the same path. This will explain why most of the comets which visit us are seen only once. Those which move in ellipses,




as Encke's and Halley's comets, will like planets pass the sun an indefinite number of times, and can thus be seen from the earth whenever they are in the part of their orbit where they were first seen. In the case of those which move in parabolas the curve is so situated that the sun lies near its vertex. A comet first becomes visible from the earth when it is advancing towards the sun along one of the branches of the curve. After passing the sun, it retreats along the other branch, and gradually disappears from view. The nearer it approaches to the sun the more does its velocity increase, and as it recedes from the sun its velocity gradually diminishes. A comet consists of a central part or head and a tail, which by some astronomers is supposed to consist of a stream of vapour produced by the action of the sun's heat on the solid portion of the comet. The tail therefore increases in size as the body approaches the sun, and its direction is such that in all positions of the comet the tail points outward from the sun. The following extract from Sir Robert S. Ball's *Star Land*, explaining the motion of comets, will be read with interest:

'Why one of these mysterious wanderers should approach

in such a hurry, and then why it should fly back again, can be partially explained without the aid of mathematics. Let us suppose that, at a distance of thousands of millions of miles, there floated a mass of flimsy material resembling that from which comets are made. Notwithstanding its vast distance from the sun, the attraction of that great body will extend thither. It is true the pull of the sun on the comet will be of the feeblest and slightest description, on account of the enormously great distance. Still the comet will respond in some degree, and will commence gradually to move in the direction in which the sun invites it. Perhaps centuries, or perhaps thousands, or even tens of thousands of years will elapse before the object has gained the solar system. By that time its speed will have been augmented to such a degree that after a terrific whirl round the sun, it will at once fly off again along the other branch of the parabola. Perhaps you will wonder why it does not tumble straight into the sun. It would do so, no doubt, if it started at first from a position of rest; generally, however, the comet has a motion to begin with which would not be directed exactly to the sun. This it is which causes the comet to miss actually hitting the sun.'

From observations on the spectrum of comets astronomers have been able to learn something as to their physical condition, and to find out some of the chemical elements which are present in them. The head of a comet gives a spectrum which indicates the presence of a glowing gas. It consists of a small number of bright lines superimposed upon a faint continuous spectrum. The spectrum also shows that the tail of a comet is not self-luminous, but that it shines by scattered sunlight. The comet of 1882 is the most instructive in regard to the materials of which comets are composed. In India, this comet formed a very conspicuous object in the sky before sunrise during the autumn of the year just mentioned. Its spectrum showed the presence of carbon, sodium, and iron. The

interest which chiefly attaches to such discoveries lies in the fact that they point to a unity in the materials of which the different bodies in the universe are composed.

Professor Tait regards comets as consisting of a mass of meteorites. In support of this opinion he refers to the fact that meteorites are always observed to follow the track of a known comet. He states that it can be mathematically proved that a swarm of such meteorites, not necessarily closely packed, but of sufficient depth, would when illuminated by the sun give half as much light as a solid slab of the same material. This would be sufficient to account for the amount of light which we receive from comets; and the feebly continuous spectrum would be that of the sunlight which the swarm reflects. The appearance presented by such a mass would be similar to that of a cloud of dust illuminated by the sun and seen from a distance. The masses might individually be as large as bricks, since bodies of that size would only be regarded as dust in the solar system. The spectrum of the head of a comet, as we have seen, shows from its bright lines the presence of a glowing gas. The impact of the masses on one another would, as Professor Tait explains, be sufficient to account for this. This impact would be produced by the velocities arising (1) from their following different paths round the sun, (2) from the velocity due to gravitation. The motion due to a velocity of 1400 feet per second, if converted into heat, would be sufficient to produce incandescence, melting, or the development of glowing gas, and the crushing of the colliding bodies.

The revelations of the spectroscope, in regard to the nature of the nebulæ, are also of a very interesting character. The nebulæ are very faint objects, and require the aid of the most powerful telescopes to render them visible. Sir R. S. Ball's description of the nebulæ is as follows: 'They are what are called nebulæ, or little clouds; and they are justly called little in one sense, for

each of them occupies but a very small spot in the sky as compared with that which would be filled by an ordinary cloud in our air. The nebulæ are, however, objects of the most stupendous proportion. Were our earth and thousands of millions of bodies quite as big all put together they would not be nearly so great as one of these nebulæ. Astronomers reckon up the various nebulæ by thousands.' Only one of the many thousands is visible to the naked eye, that, namely, in the constellation of Andromeda. The spectra of the nebulæ consist of bright lines, showing that they are in the condition of luminous gases. The lines also show that hydrogen in some form is a constituent of these very distant objects, and that nitrogen is also present.

We shall now endeavour to explain the manner in which the spectroscope has been applied to ascertain whether a star or other luminous heavenly body is approaching or receding from the earth. We have already stated that light is regarded as consisting of the vibrations of an invisible medium which pervades the whole of space, and that these vibrations may be conceived to resemble the waves which are produced on the surface of still water when a stone is dropped into the water, or when the surface of a lake is agitated by the wind. Suppose then a boat to start from the side of a lake in a direction opposite to the wind, which will also be the direction contrary to that in which the waves are advancing. As the boat moves along it will meet more waves every minute than if it had been at rest waiting for the waves to come up to it. Similarly, if the boat is going in the same direction as the waves, fewer of them will pass it in a minute than if the boat were stationary. We may easily conceive it to be moving with the waves at the same rate as they are travelling, in which case it will be carried along on the top of a single wave and no others will pass it. Sound, as well as light, is produced by vibrations. In the case of sound, the vibrations are those of air. If we are moving towards a

sounding body which is giving out a particular note, more waves of sound will enter the ear every second than if we were standing still. The same thing will happen if the sounding body is moving towards us. The pitch of any particular note is higher the greater the number of waves which reach the ear per second, and lower when the number is smaller. This has been experimentally verified in the following manner: A trumpeter accompanied by a musician was stationed on a railway engine. The trumpeter had to sound a certain note, and the musician by his side was able to certify that the note which had been agreed upon was actually played. Other musicians were stationed by the side of the line whose business it was to listen to the note of the trumpet, and to state what the actual note was which they heard. These latter ascertained that the note appeared higher than the one played by the trumpet when the engine was coming towards them, and that the more quickly the engine approached the higher the note appeared. When, on the contrary, the engine went away from them the note appeared lower. This will enable us to understand what happens under similar circumstances in the case of waves of light. When a luminous body moves towards the observer more waves of light will enter his eye every second than can do so when the observer and body are at relative rest with respect to one another. This will be equivalent to an increase in the frequency of the vibrations or a shortening of the wave-length. We have seen that the lines produced by light of a given wave-length occupy a fixed position on the spectrum. If, therefore, the wave-length be shortened, as it would be if the luminous body were approaching, the line or lines would be shifted towards the violet, or more refrangible end of the spectrum. If, on the contrary, the frequency of the vibration be diminished or the wave-length be increased, on account of the body receding from the observer, the lines would shift in the direction of the red

or less refrangible end of the spectrum. Suppose, for example, that the light from a certain star gives the line peculiar to hydrogen. This spectrum would be placed side by side with a standard hydrogen spectrum. If the hydrogen line in the star spectrum did not quite coincide with the same line in the standard one, but shifted a little towards the violet, this would show that the star was moving towards the earth; and if the line were displaced in the direction of the red end, the inference would be that the star was receding from the earth. The first application of this method to the study of the relative motion of the stars with reference to the solar system was made by Dr. Huggins. He found that Sirius is receding from the earth at the rate of forty-one miles per second. On using a spectroscope of greater delicacy, he afterwards ascertained that many other fixed stars are moving some towards, and others away from, the earth.

We see, then, that the light which comes from a star is capable of showing whether the star is moving towards or away from us.

The same principle can be used to verify the rotation of the sun on its axis. This rotation is inferred in another manner from the behaviour of sun-spots. The rotation is in the same direction as that of the earth; consequently the left-hand side of the sun is coming towards us, and the right-hand side moving away. If, then, the sun has a rotation of this nature, any given ray of light coming from the left-hand side of the sun ought to show an increase of refrangibility when examined by the spectroscope, and a ray from the right a decrease. It is found that the hydrogen line from the left is deflected a little towards the violet, and that from the right a little in the opposite direction. This is consistent with the rotation which we have here supposed, and which is otherwise known to exist.

The short account here given of this most interesting subject of spectrum analysis may be appropriately closed by

an extract from Newcomb's *Astronomy*, in which the principles of spectrum analysis are very concisely stated:—

'The reader now understands that when the light from a celestial object is analysed by the prism, and the component colours are spread out singly as on a sheet, the dark and bright lines which we see are the letters of the open book which we are to interpret so as to learn what they tell us of the body from which the light came, or the vapours through which it passed. When we see a line, or a set of lines, which we recognise as produced by a substance, we infer the presence of that substance. The question may now be asked, How do we know but that the lines we observe may be produced by other substances besides those which we find to produce them in our laboratories? May not the same lines be produced by different substances? This question can be answered only by an appeal to probabilities. The evidence in the case is much the same as that by which, recognising the picture of a friend, we conclude that it is not the picture of some one else. For anything that we can prove to the contrary, another person might have exactly the same features, and might therefore make the very same picture. But, as a matter of fact, we know that practically no two men whom we have ever seen do look exactly alike, and it is extremely improbable that they ever would look so. The case is the same in spectrum analysis. Among the great number of substances which have been examined with the spectroscope, no two give the same lines. It is, therefore, extremely improbable that a given system of bright lines could be produced by more than one substance. At the same time the evidence of the spectroscope is not necessarily conclusive in all cases. Should only a single line of a substance be found in the spectrum of a star or nebula, it would hardly be safe to conclude from that alone that the line was really produced by the known substance. Collateral evidence might, however, come in. If the same line were found both in the sun-light and in that of a

great number of stars, we should be justified in concluding that the lines were all produced by the same substance. All we can say in doubtful cases is that our conclusions must be drawn with care and discrimination, and must accord with the probabilities of each special case.'

# GASES

# GASES

ALTHOUGH many gases are invisible, it is not to be supposed that they are devoid of the properties of matter as we understand it.

It is certain that every substance, however hard or fire-proof, could be converted into a gas, provided it were possible to obtain a temperature sufficiently high for this purpose. The three different states which matter is capable of assuming are the solid, the liquid, and the gaseous. Though various kinds of liquids and solids have been clearly recognised from a very early period, it is only in comparatively recent times that men have come to recognise that there are many kinds of gases.

It might be thought that since most gases are invisible there would be no possibility of distinguishing one from another; and undoubtedly this would be the case if the distinction depended on the colour of these gases, since they are absolutely without colour. Other means fortunately can be employed by the chemist to clearly mark off one gas from another.

For example, Professor Black of Edinburgh, in 1750, found that when a dilute acid is poured on marble a gas is given off; and this gas Black named 'fixed air,' because it is fixed in alkali carbonates, such as carbonate of sodium or potassium. Marble has the same chemical composition as chalk, and is termed carbonate of calcium. When either marble or chalk is raised to a high temperature, more or less of this fixed air is liberated. It is quite easy to collect this gas, which is now popularly named carbonic acid gas. It is found that this gas does not, like

air, support combustion. A burning taper plunged into a jar containing carbonic acid gas is at once extinguished. Again, if some of this gas be passed into a clear solution of lime water, a white substance is immediately formed. This substance is carbonate of calcium.

Carbonic acid is also heavier than air. It can be poured downwards from a jar containing it. This can easily be seen by pouring it on to a burning candle. The flame will at once be extinguished.

If a glass beaker be placed at one end of the beam of a delicate balance and equipoised, it will be found that when the air in the beaker is displaced by pouring carbonic acid gas into it, the arm of the balance to which the beaker is attached will descend. This also proves that the gas is heavier than air. It may also be transferred from one vessel to another, like a liquid, by means of a siphon. In 1766 Cavendish showed that a gas, now named hydrogen, but which he termed inflammable air, and which is easily obtained by pouring dilute acids, such as sulphuric and hydrochloric acids, on zinc, or iron, is likewise a distinct substance.

It is the lightest known substance, being more than fourteen times as light as air.

It can easily be poured upwards. This can be proved by means of the balance; for if a beaker, with mouth downwards, be equipoised by weights in the other pan of the balance, and hydrogen be poured up into the beaker the arm of the balance to which the beaker is attached will ascend.

If soap bubbles are filled with hydrogen they will immediately mount upwards.

Cavendish also found that when a light was applied to this gas it burned with a pale flame. When about to apply a light to this gas it must first be ascertained that it is free from admixture with air, otherwise a dangerous explosion may take place.

These properties, both chemical and physical, serve to clearly distinguish this peculiar gas from all others.

On the first of August 1774, Dr. Priestley heated some oxide of mercury, or, as it was then named, red precipitate. In order to get the pretty high temperature needed for this experiment, Priestley concentrated the sun's rays on the red precipitate by means of a burning glass. The gas given off by this process was quite colourless, just as we have seen in the case as regards carbonic acid and hydrogen. It is, however, found to possess very distinctive properties. For instance, a red chip of wood when plunged into the gas, is at once kindled, and fine iron wire, or a watch spring, which cannot be burned in air, burn with much brilliancy in this gas, which he termed oxygen. This gas forms a constituent part of the atmosphere, and is absolutely essential for the existence of animals and plants. The distinction between these gases is ascertained by means of experiments, and the means adopted for this purpose is termed the Experimental Method.

By means of experiments, nature is as it were questioned by modifications of the ordinary conditions, and by this means results are obtained different from those which are otherwise to be met with. It would be incorrect to say that any science is purely observational; for though, for instance, it is not possible to class astronomy as an experimental science in the same way as chemistry, nevertheless the experimental method is employed in certain researches in connection with the heavenly bodies.

Though chemistry is essentially an experimental science, the experiments are carried on, not in a haphazard, but in a systematic manner. Conclusions are arrived at from the experimental results which enable chemists to make predictions regarding new compounds or undiscovered elements. These predictions have not seldom been fulfilled. It is this power of prediction and subsequent verification that makes the experimental sciences, not dry catalogues of disjointed facts, but interesting super-

structures whose various parts are fitted together by Nature herself and not by the arbitrary will of man.

Physicists have long known that certain gases, such as steam, or vapours of other liquids, can easily be liquefied, and further researches in this direction led them to predict that all gases are merely vapours, and could be liquefied under certain conditions. As will be seen later on, this prediction has been amply verified.

The gaseous condition of matter has been defined as that which is capable of indefinite expansion; that is to say, however large a vacuous closed space may be into which the smallest possible quantity of gas is introduced, the gas will become uniformly distributed throughout the closed vacuous space.

Gases obey certain laws, both in regard to temperature and pressure. If the temperature of a gas remain constant, the relation between the volume and pressure as formulated by Boyle in 1662, is as follows: *The volume of a gas varies inversely as the pressure*; or this may be expressed by saying that the volume of a gas is proportional to its density. For example, if 100 cubic centimetres of air at 0°C., and under a pressure of 76 centimetres mercury, are taken, find how many centimetres they will occupy under a pressure of 152 centimetres of mercury. It is to be observed that the product $pv$, when $p$ stands for the normal pressure and $v$ for volume under normal pressure, is a constant quantity, and expresses Boyle's law, therefore $pv = p'v'$, where $p'$ stands for a pressure different from the normal pressure and $v'$ for the corresponding volume. We can therefore work the above example:

$$100 \times 76 = v' \times 152, \text{ or } v' = 50 \text{ cubic centimetres.}$$

In this case the pressure is doubled, and the volume is reduced by one-half.

If different gases which do not act chemically on each other are mixed together, and are introduced into a vessel, the pressure exerted on the vessel is the sum of the separate pressures of the different gases. For example,

if fifty cubic centimetres of nitrogen are introduced into a vacuous vessel, they will exert a certain pressure on every square centimetre of the vessel depending on its capacity, and if in addition twenty cubic centimetres of oxygen are introduced, they will also exert a certain pressure on each square centimetre of the vessel. Now the total pressure on each square centimetre is the sum of the pressures exerted by the nitrogen and oxygen separately.

Boyle's law is only approximately true; though for most ordinary purposes it may be asserted to be true; that is, the density varies directly as the pressure up to a certain point.

The careful investigations of Oersted, Despretz, Dulong, Regnault, Andrews, Cailletet, Amagat, and others, have shown that the law is only approximate for every known gas, and that the deviation from the law is different for each gas. Cailletet and Amagat have investigated the deviations from the law when the gases were subjected to higher pressures than were employed by any previous experimenters.

The gas was subjected to a pressure of a mercury column enclosed in a strong steel tube. Oxygen acts rapidly on mercury when under a high pressure, and for this reason nitrogen gas was used. In this way Cailletet reached a pressure of 182 metres of mercury, and Amagat a pressure of nearly 330.

Amagat also determined the corresponding pressures and densities for other gases, by a method which avoided the errors which would occur from the action of the gases on mercury.

In all gases except hydrogen the product $pv$ (pressure by volume) instead of being constant, as is required by Boyle's law, diminishes at first as the pressure increases. At a certain pressure, which differs for each gas, the diminution stops, and if the pressure be then further increased, the product $pv$ increases as well as the pressure, and goes on increasing up to the greatest pressure used;

but in the case of hydrogen the product increases from the very beginning, no diminution taking place as with other gases. For example, a thousand volumes of hydrogen at the pressure of one atmosphere will not be reduced to one volume under a pressure of one thousand atmospheres, but will occupy a larger volume than one. Only 623 volumes of hydrogen at a pressure of one atmosphere can be reduced to one volume at a pressure of one thousand atmospheres. If, however, fifty litres of hydrogen at a pressure of one atmosphere be subjected to a pressure of fifty atmospheres, they will be reduced to one litre. It will thus be seen that Boyle's law is true for tolerably high pressures, though when the pressure employed is very high a considerable deviation occurs. A further very important property of gases is to be observed.

If the pressure on a gas be largely increased, and the temperature at the same time reduced to a low point, all gases undergo sudden contraction, and are changed into liquids. Chlorine was the first gas that was changed into a liquid. Northmore succeeded in liquefying this gas in 1806. The subject was soon afterwards taken up by Faraday, who showed that other gases, such as carbonic acid, sulphurous acid, ammonia, nitrous oxide, cyanogen, and hydrochloric acid gases were capable of being reduced to liquids.

In his experiments, Faraday made use of tubes made of strong glass, and in one limb of these tubes, which was closed at the end, materials were placed which yielded the gas on the application of heat. The open limb of the tube was then closed by means of the blowpipe, and the gas was evolved by applying heat to the other end. The liquefaction of the gas was caused by the pressure exerted by the gas itself, when thus generated in a closed space. Not only can the liquefaction of some gases be brought about by a high pressure, but also by a low temperature. For example, if the temperature of sulphurous acid gas at the ordinary pressure of the atmosphere, be reduced to

—10°C., it becomes a liquid, and when the temperature is still further reduced until it reaches —76°C., the liquid freezes and becomes a mass of ice. Up to a recent period certain gases such as hydrogen, oxygen, and nitrogen, had withstood every attempt to change them into the liquid condition, and for this reason they were named the permanent gases.

In 1877, Cailletet succeeded in liquefying both oxygen and carbonic oxide at his works in Chatillon-sur-Seine; and Pictet of Geneva about the same time had also liquefied oxygen.

At the close of 1877, and beginning of 1878, not only hydrogen, but all the so-called permanent gases were condensed to the liquid condition. It is remarkable that these important results were arrived at by these experimenters quite independently, though each had devoted a considerable amount of study to the subject for many years.

Cailletet is an extensive iron-master in France, while Pictet is extensively engaged in the manufacture of machinery for the production of ice. Doubtless the experience acquired by each in his own business greatly assisted in enabling him to devise means which finally succeeded in bringing about such exceedingly interesting results.

The process adopted by each experimenter consisted in subjecting the gas to a very high pressure, and at the same time in reducing the temperature to a very low point. Every gas must be below a certain temperature before liquefaction can occur, however great the pressure may be that is applied.

This temperature was termed by the late Professor Andrews of Belfast the 'critical point.' Of course this critical point is different for different gases. Before Cailletet and Pictet's successful experiments, no former experimenter had succeeded in reducing the temperature of the so-called permanent gases low enough to reach the

critical point, and it therefore happened that however high a pressure such a gas as oxygen was subjected to, it could not be changed into the liquid state.

The apparatus used by the two experimenters was very different. Pictet evolved the gas in a wrought-iron tube of great strength in order to be capable of withstanding an enormous tension, while Cailletet subjected the gas to great pressure by means of a hydraulic press. In order to obtain a low temperature, Pictet caused liquid carbonic acid gas to evaporate rapidly. The apparatus he employed for this purpose is best understood by actually seeing it in operation.

It is perhaps unnecessary to state that rapid evaporation produces great cold. Ether, which is a volatile body, when poured on the hand, produces a sensation of cold, owing to its rapid evaporation.

The rapid evaporation of the carbonic acid in Pictet's apparatus cooled the gas, under great pressure, below the critical point, viz., to a constant temperature of $-130°C$. It then became changed to the liquid state.

Cailletet succeeded in cooling the gas below the critical point by suddenly diminishing the pressure upon the gas. The sudden expansion of the gas produced a rapid diminution of the temperature, brought about by the transference of heat into the motion of the particles of the rapidly expanding gas. In this way the temperature of the particles sank below the critical point, and the finely-divided liquid oxygen or hydrogen appeared in the form of a mist in the tube in which either of these gases was contained.

More recent researches on the liquefaction of gases have considerably added to our knowledge of the subject.

Before the successful liquefaction of the permanent gases, the view had been frequently expressed that the power of adhesive attraction belonged to all bodies without exception, and like many other predictions in science, this has been completely verified by the experiments of Cailletet and Pictet.

### Law of Charles.

This law, which is named after its discoverer, states that all gases measured under constant pressure expand equally for equal increments of heat, or at constant pressure every gas expands by the same fraction of itself for a given rise from a given temperature. This is often called the law of Gay-Lussac or of Dalton; for though Charles discovered the law, he did not publish his results, and the law did not become generally known till fifteen years after Charles discovered it, when Gay-Lussac and Dalton working independently re-discovered it. These results were published in 1801 and 1802, Dalton's at the earlier date. It is upon the authority of Gay-Lussac, who accidentally became acquainted with the fact of its previous discovery, that the law is named after Charles.

According to this law all gases measured under constant pressure expand in such a way that one volume at 0°C. becomes 1·3665 at 100°C., so that the coefficient of expansion of gases is 0·003665 for an increase of temperature from 0°C. to 1°C. Careful experiments by Magnus, Regnault, Jolly, and others show that there is an appreciable difference in the coefficient of expansion for different gases; though this applies chiefly to the more easily liquefiable gases; the difference between such gases as oxygen and hydrogen being but slight. Boyle's law may in ordinary calculations be combined with that of Charles, when within the limits of not very high pressure we get $\frac{pv}{T}$ a constant quantity: T being the temperature measured from absolute zero which is between 273°C. and 274°C. below the freezing-point. For example, 100 cubic centimetres of a gas under a pressure of one atmosphere, or a column of mercury 76 centimetres long, and at the freezing-point will become, when subjected to a pressure of a mercury column, 150 centimetres in length and to a temperature of 100° C., nearly 69 cubic centimetres.

Thus $\frac{100 \times 76}{273} = \frac{v \times 150}{273 + 100}$, or $v = 69$, nearly.

It should be here mentioned that the thermometer invariably used in science is the Centigrade, whose freezing-point is marked zero and boiling-point 100°. Unfortunately the thermometer in common use in Britain and some other countries is Fahrenheit's. The disadvantage arising from the use of Fahrenheit's thermometer is the arbitrary way in which it is graduated. Freezing-point is indicated by 32°, and boiling-point by 212°. Zero on Fahrenheit's scale signifies 32° of frost. Between freezing-point and boiling-point there are 180°. It is, however, easy to convert one scale into another. In Fahrenheit 180° correspond to 100° Centigrade. The length of a degree Fahrenheit is therefore $\frac{100}{180}$ or $\frac{5}{9}$ths of a degree Centigrade. To convert any temperature indicated by a Fahrenheit thermometer to the corresponding temperature Centigrade, subtract 32 and multiply the remainder by $\frac{5}{9}$. For example, convert 77° F. to Centigrade. Here $(77° - 32°) \times \frac{5}{9} = 25°$ C.

To convert Centigrade readings to Fahrenheit, multiply the Centigrade degrees by $\frac{9}{5}$ and add 32 to the product. Find the Fahrenheit reading corresponding to 55° Centigrade; $55 \times \frac{9}{5} + 32 = 131°$ F.

Another thermometer largely in common use in Europe is termed Réaumur's. The number of degrees between the freezing- and boiling- points in Réaumur's is 80°. Zero indicates the freezing-point and 80° the boiling-point. A Fahrenheit degree is only $\frac{4}{9}$ths as long as a Réaumur, and a Centigrade degree is only $\frac{4}{5}$ths as long. To convert Centigrade degrees to Réaumur multiply the Centigrade reading by $\frac{4}{5}$. For example, 80° C. $= 80 \times \frac{4}{5}$ or 64° R. To convert R. to C. multiply the Réaumur reading by $\frac{5}{4}$.

To change a Fahrenheit reading to Réaumur, subtract 32 and multiply the difference by $\frac{4}{9}$. For example, 113° F. $= (113 - 32) \times \frac{4}{9}$ or 36° R. Again, to convert R. to F. multiply by $\frac{9}{4}$ and add 32 to product. Owing to the fact that the Fahrenheit scale was the one used by the older experimenters, it is desirable to have some practice in

working out examples when this scale is used. It has been stated that the temperature measured from absolute zero to the freezing-point on the Centigrade scale is about 273°. Now $273 \times \frac{9}{5}$ or 491·4 is the number representing absolute zero on the Fahrenheit scale, and since the absolute zero Centigrade is a little over 273°C., Fahrenheit may be conveniently taken as 492°; that is, the absolute zero on the Fahrenheit scale is 492° below freezing-point or 460° below zero. Since $273+t$, when $t$ represents the temperature on the Centigrade scale, is called the absolute temperature, $460+t$ represents the absolute temperature on the Fahrenheit scale—$t$ in this case representing the temperature on the Fahrenheit scale. We have seen that 0·003665 is the coefficient of expansion for gases for an increase of one degree, so that if $V°$ represents the volume of a gas at zero $V°(1·003665)$ will be the volume at 1°, and $V°(1·003665t)$ will be the volume at $t°$. Now $1 \div 0·003665$ or 273° is called the reciprocal of the coefficient of expansion, and $273°+t$ is the absolute temperature of the gas on the Centigrade scale. Taking the Fahrenheit scale, 0·002036 is the coefficient of expansion, and $1 \div 0·002036$ gives over 491, which, for convenience, may be taken without much error as 492; hence on the Fahrenheit scale 492 is the reciprocal of the coefficient of expansion. Taking the Centigrade scale, this means that if 273 volumes of a gas at 0° are raised one degree in temperature, they become 274, and so on. If, on the other hand, 273 volumes are reduced one degree they become 272, and so on. Reasoning in this way it would appear that if 273 volumes at 0°C. were cooled down to 273°, they would occupy no space. This, of course, would be impossible; but we have no means of knowing what would be the condition of matter deprived of all its heat.

In the same way 492 volumes at 32° Fahrenheit would become 493 volumes at 33°, at $-32°$, 492 volumes would be reduced to 460 volumes, and so on.

Now if $T$ represent the absolute temperature, $T=$

$273+t$ Centigrade, and $460+t$ Fahrenheit; since on the Fahrenheit scale the freezing-point is 32° above zero, it is more convenient to take the temperature from absolute zero to the zero point on the scale, and this is 492°−32°, or 460°; hence $460+t$ is the absolute temperature on the Fahrenheit scale.

We will now work a few examples.

If 200 cubic inches of a gas, whose temperature is 60° F. and pressure 30 in., be raised in temperature to 280° F., and its pressure reduced to 20 in., calculate their volume.

$$\frac{pv}{460+t}=\frac{p'v'}{460+t'}, \text{ therefore } \frac{30\times 200}{520}=\frac{20v'}{740},$$

hence $v'=426{\cdot}9$ cubic inches.

Again, if 20 cubic inches of air, whose temperature is 56°F. and elastic force 28·8 inches, be expanded to 25 inches by the application of heat, and if the elastic force become 31 inches, calculate the temperature.

$$\frac{28{\cdot}8\times 20}{460+56}=\frac{31\times 25}{460+t}, \text{ or } \frac{144}{129}=\frac{775}{460+t},$$

therefore $144t=33735$ and $t=33735\div 144$, or $t=234{\cdot}27$°F.

Let 100 cubic inches of air have a temperature of 32°F. and pressure of 29·922 in.; if the temperature become 60°F., and the pressure 30 inches, calculate the volume.

$$\frac{29{\cdot}922\times 100}{460+32}=\frac{30v}{460+60}, \text{ therefore } \frac{1496{\cdot}1}{246}=\frac{3v}{52},$$

hence $v=77797{\cdot}2\div 738=105{\cdot}4162$ cubic inches.

Calculate the volume of 1 lb. of air at the temperature 72°F. and pressure 29 inches.

Since 100 cubic inches of air at pressure 30 inches and temperature 60°F. have been found experimentally to amount to 31·0117 grains, 1 cubic inch equals 0·310117 grain. There are 1728 cubic inches in a cubic foot, therefore, 0·310117 × 1728, or 535·892176, grains are the mass contained in a cubic foot of air, measured at a temperature of 60°F., and under a pressure of 30 inches. But 1 lb. of air equals 7000 grains, therefore 535·892176 ÷7000, or 0·07655 lb., equals the mass in pounds contained in a cubic foot of air at temperature 60° F. and

30 inches pressure. At this temperature and pressure therefore, 0·076556 lb. equals 1 cubic foot,

hence 1 lb. $= \frac{1}{0·076556}$ cubic foot.

$$\text{But } \frac{1}{0·076556} \times \frac{30}{520} = \frac{29}{532} \frac{v}{},$$

$$\text{and } v = \frac{1}{0·076556} \times \frac{30}{520} \times \frac{532}{29} = \frac{399}{28·861612},$$

or $v = 13·825$ cubic feet; where $v$ = volume.

As another example, take the following:—

The dimensions of a chamber are 21 feet by 18 and 13 feet high, and the barometer stands at $29\frac{1}{2}$ inches, calculate the mass of air in it, its temperature being 65°F.

Let $M$ = mass, 0·076556 lb. is the mass of air contained in 1 cubic foot, at a temperature of 60°F., and pressure 30 inches, hence 1 lb. equals volume $\frac{1}{0·076556}$ in cubic feet, and $M$ lbs $= \frac{M}{0·076556}$ cubic feet at 60·F. and 30 in. pressure, therefore $\frac{M}{0·076556} \times \frac{30}{520} = \frac{4914}{525} \times \frac{59}{2}$, where 4914 = dimensions of chamber in cubic feet. From this we obtain

$$M = \frac{4914}{525} \times \frac{59}{2} \times \frac{520}{30} \times 0·076556,$$

or $M = 64120·549584 \div 175$, or 366·403 lbs.

These examples are sufficient to show that the use of the Fahrenheit thermometer and English measure of mass make the calculations somewhat laborious. The Centigrade thermometer and French measurement of mass are now universally employed in science; though a knowledge of the methods of calculation (when the Fahrenheit scale is used to indicate temperature and grain, lbs., etc., are used to measure mass), is necessary in order to be able to understand works in which this system of calculation is employed.

When the Centigrade scale is used $273 + t$ is called, as has been said, the absolute temperature, and $\frac{pv}{T} = \frac{p'v'}{T'}$, where $T = 273 + t$, and $T' = 273 + t'$; $\frac{p\,v}{T}$ is a constant quantity within the range of moderate pressures.

Regnault has shown that the mass of a litre of dry air at 0°C. and 76 centimetres pressure is equal to 1·293187 grammes at Paris.

If $M$ be the mass of dry air at this temperature and pressure, $\frac{M}{1\cdot293187}$ is the volume of the mass $M$ at 0°C., and 76 cm pressure; hence

$$\frac{p\,v}{273+t}=\frac{76M}{1\cdot293187}\times\frac{1}{273}.$$

For example. Find the volume of 100 grammes of dry air, at a temperature of 10°C. and pressure 60 centimetres.

$$\frac{60\times v}{283}=\frac{100\times76}{1\cdot293187}\times\frac{1}{273}$$

$$v=77\cdot32\times\frac{19}{15}\times\frac{283}{273},\text{ or } v=101\cdot52 \text{ litres.}$$

Again, find the mass contained in 130 litres of air, measured at 30°C. and 36 centimetres pressure.

$\frac{M}{1\cdot293187}\times\frac{76}{273}$ is a constant quantity.

In the example, therefore,

$$\frac{M}{1\cdot293187}\times\frac{76}{273}=\frac{130\times36}{303}\text{, hence,}$$

$$M=\frac{130}{303}\times\frac{9}{19}\times273\times1\cdot293187$$

$$=413056\cdot85967\div5757,$$

$$\text{or } M=71\cdot74863 \text{ grammes.}$$

Once more, find at what temperature 71·74843 grammes of air, at a pressure of 36 cm, must be measured so that the volume may be 130 litres.

$$71\cdot74863\div1\cdot293187=55\cdot4 \text{ litres at 0°C. and 76 cm.,}$$

$$\text{therefore } 55\cdot4\times\frac{76}{273}=130\times\frac{36}{273+t},$$

$$\text{or } 55\cdot4\times\frac{19}{273}=130\times\frac{9}{273+t},$$

$$\text{hence } 319410=287359\cdot8+1052\cdot6t,$$

$$1052\cdot6t=32050\cdot2,$$

$$t=32050\cdot2\div1052\cdot6,\text{ or } t=30°\text{C},$$

## THE CONTINUITY OF THE GASEOUS AND LIQUID STATES.

When water or other liquid evaporates in closed vessels, it is well known that the tension of the vapour increases at a very rapid rate as the temperature increases, and that the density of the vapour at the same time undergoes a similar rapid increase. In the case of water in contact with steam, as in the boiler of a steam-engine, at a temperature of 231°C., the weight of a cubic metre of steam is $\frac{1}{82}$ part of a cubic metre of water at the point of maximum density of 4°C., the weight of steam at 100° being no more than $\frac{1}{1700}$ of the same bulk of water; and since water expands when heated, the weight of the water in contact with steam at 230° C. is not much greater than the weight of the steam with which it is in contact. From this result it is evident that under these circumstances, when the water changes from the gaseous to the liquid state, there is no condensation or diminution in volume, and in such a case there can be no distinction between the gaseous and liquid conditions of matter.

In 1822, Cagniard de la Tour heated liquids sealed up in glass tubes, whose capacity was nearly equal to the volume of the liquid which they contained. When a tube was one-fourth filled with water and heated to 360°C. the water all disappeared, and the tube appeared to be empty, but as the vapour cooled, at a certain point a kind of cloud appeared and the liquid gradually became again visible. It was thought by Cagniard de la Tour that the substance assumed the gaseous condition when heated, but the late Dr. Andrews of Belfast has demonstrated that in such an experiment the properties of the liquid and vapour gradually approach one another, and that at a given temperature it is not possible to distinguish the properties of the two states. It is clear from this that until this particular temperature is reached, the gaseous and liquid states are quite distinguishable, and will remain so however great the pressure may be to which the gas is

subjected. It is only when the gas is reduced below the temperature, which Andrews named the critical point, that the change which is termed liquefaction can be produced. In the case of oxygen, hydrogen, nitrogen, and other gases difficult to liquefy, the critical point is so low that it cannot be reached by the ordinary methods of cooling a gas. Pictet, as we have seen, cooled oxygen gas to —140°C. by the rapid evaporation of liquid carbonic acid and nitrous oxide gases. The same object was attained by Cailletet by diminishing the pressure on the highly compressed oxygen or hydrogen, and allowing it to expand suddenly, the temperature in consequence sinking so low that a condensation of the gas to a liquid occurred.

It is, however, possible to observe with ease the critical temperatures of many gases, owing to their critical temperatures not being nearly so low as that of the so-called permanent gases. For example, the critical point of carbonic acid gas is 30·92°C., and at all temperatures above that point no condensation of the gas to a liquid is possible. If the pressure on carbonic acid gas is gradually raised to 150 atmospheres the volume steadily diminishes, but no sudden diminution takes place at any stage of the increase of pressure. If the temperature is now allowed to fall until the carbonic acid has reached the temperature of the air, the gas will have assumed the liquid form. It will be seen from this that, by means of a series of gradual changes, during which no abrupt alteration of volume, or evolution of heat occurs, the gas finally becomes converted into a liquid.

It is evident from this that the properties of a gas can, by a continuous and gradual process, be changed to those of a liquid.

### The Kinetic Theory of Gases.

It will be seen under what has been written about 'Energy' that heat is only a kind of motion, so that a hot body is hot by reason of possessing a store of energy, some

portion of which can be used for the production of useful work. In dynamics the energy of motion is termed kinetic energy (from Greek *kinein*, to move), and if the body possessing this energy is brought to rest by contact with another body its energy is communicated to the other body, or changed into heat.

It must be borne in mind that the energy arising from the motion of a body in the form of heat does not affect the motion of the mass of the body. The motion cannot be seen, and is only a matter of inference, though the conclusion arrived at is as certain as if the motion of the molecules of which the body is made up were as visible as the waves of the sea. No body is absolutely at rest, but every kind of matter is, as regards its molecules, in a condition of ceaseless motion whose energy depends on its temperature. The molecules may consist of a collection of smaller parts termed atoms, which as a whole partake of the motion of the molecules. In ancient times the attention of some acute thinkers was devoted to this invisible motion of the molecules. Lucretius, the celebrated Latin poet, asserts that the different properties of matter depend on the motion of its ultimate elements or atoms.

Daniel Bernoulli first conceived the idea that the pressure of the air on the walls of a vessel containing it could be explained by the impact of its particles on the vessel; and the late Dr. Joule of Manchester, in 1841, proved the correctness of Bernoulli's idea, and calculated the mean velocity of the molecules corresponding to a given pressure.

Since 1841, Clausius of Germany, Clerk Maxwell of Cambridge, and numerous other physicists, have completed the dynamical theory of gases.

What is termed 'diffusion' of gases and liquids is due to the movements of the molecules, or small particles of matter, of which these forms of matter are composed.

These molecules move with great velocity, and the

motion, unless acted on by external forces, is uniform and rectilinear. As may be supposed, the molecules frequently come in contact with each other, or frequent collisions occur. It might be inferred from this that a loss of energy would result, but such is not the case; for no loss of the total energy can occur provided that no change of temperature takes place.

From the kinetic theory of gases the law deduced by Guy-Lussac that the densities of gases are proportional to their molecular weights, is expressed by the statement that when two gases are at the same temperature and pressure, the number of molecules in the unit volume is the same in both gases.

The law of the equal expansion of gases, and the laws of diffusion and effusion can also be deduced from the kinetic theory.

The complete treatment of the subject involves the use of somewhat abstruse mathematical reasoning; though the principles involved are quite intelligible without the aid of mathematics.

### Diffusion of Gases.

It was observed at an early period in the history of gaseous chemistry that when gases differing in their specific gravities, provided they exert no chemical action on each other, are once thoroughly mixed together, they do not separate in the order of their densities when left standing for any length of time, but remain distributed quite uniformly throughout.

Dr. Priestley proved that when gases of different densities were mixed they did not separate; but he thought that if such gases as carbonic acid and hydrogen were put into a vessel, the heavier carbonic acid first and the lighter hydrogen afterwards carefully placed on the top, no mixing of the gases would take place however long they might be allowed to stand. This statement did not satisfy

Dalton, and, accordingly, in 1830, he put the question to the test by a series of experiments, and proved that a lighter gas cannot rest upon a heavier without mixing, as, for example, oil upon water, but on the contrary, he found that the particles of the two gases constantly diffuse through each other until equilibrium takes place, and this occurs quite independently of their specific gravities. Dalton considered this as a necessary consequence of his conclusions in regard to the constitution of matter; for his theory implied that the particles of all gases exert a repulsive influence on each other, and that each gas was capable of expanding into the space occupied by another exactly as it would into the same space when vacuous. This assumption of Dalton's, however, is erroneous; for the rate of diffusion of a gas into another gas is thousands of times as slow as that at which it rushes into a vacuum.

The apparatus employed by Dalton was of such a simple character that any one sufficiently interested in the subject can easily undertake simple experiments which will prove that gases actually do diffuse. Dalton's apparatus was only a few phials and corks perforated for the purpose of admitting the insertion of glass tubes. The tubes used were about ten inches in length and one-twentieth of an inch in bore; though occasionally he used tubes twenty inches long and half an inch in diameter. The phials were used to hold the gases and the glass tube formed the connection between the two gases. The heavier gas was invariably placed in the lower phial, and the two were placed in a perpendicular position, and were allowed to remain undisturbed in this position during the experiment. In this way sufficient precautions were adopted to prevent the effect of any agitation, since a narrow tube ten inches in length would effectually prevent any intermixture due to the movement of the phials at the beginning of the experiment. Any one may try an experiment of this kind by means of two small flasks fitted with perforated

caoutchouc corks. Let one flask be filled with carbonic acid gas and a similar one with hydrogen. The flask into which the carbonic acid gas is to be introduced should be filled by passing the gas into it with its neck uppermost. In this way the air will be displaced by the carbonic acid gas. The flask into which the hydrogen is to be introduced should also be filled by displacement, but in this case the neck of the flask must be held vertically downwards. Having inserted the tube on which the corks are fixed into the lower flask containing the carbonic acid gas, the flask containing the hydrogen is kept neck downwards, and the cork fixed on the upper end of the tube inserted. The flasks are allowed to remain in the vertical position, the flask containing the hydrogen being at the upper end of the tube. After being allowed to remain for a shorter or longer period the flask containing the hydrogen may be removed, and a little clear lime-water poured in. A white precipitate will be formed, which clearly shows that the heavier gas has diffused through the narrow tube and has become mixed with the hydrogen. It can also be proved that hydrogen has descended and has become mixed with the carbonic acid, though this needs more skilful management than the proof of the ascent of the carbonic acid.

Priestley, in 1809, noticed that gases passed through fine pores, such as exist in unglazed earthenware retorts, which though air-tight allow the vapour of water to pass through the fine pores. If any doubt is entertained regarding the fact of these unglazed retorts being air-tight, it will be found that no air escapes however forcibly one blows in. Dalton first explained this as being due to the same cause which brings about the intermixture of gases when a narrow glass tube forms the channel of communication, only in the case of the unglazed retorts there are a number of exceedingly minute pores instead of one.

In the year 1823, Döbereiner noticed that hydrogen gas collected over water in a large flask which happened to

have a fine crack in the glass, made its way through the crack into the air surrounding the flask, and that the level of the water in the flask was nearly three inches above that of the water in the trough. When the finely-cracked flask was filled with air and left standing no difference in the height of the water within the flask and in the trough was observed. If the flask when filled with hydrogen gas was surrounded with a jar filled with the same gas, in this case also no difference of level inside and outside the trough was observable. Döbereiner was unable to explain the results of his observations, and it was not till nine years afterwards (1832) that Professor Thomas Graham, of University College, London, showed that no hydrogen could escape by the crack without some air going in; and as the result of his experiments he enunciated the law of gaseous diffusion, viz., that the rate of diffusion is not the same for all gases, but that their *relative rates of diffusion are inversely proportional to the square roots of their densities.*

By 'inversely proportional' is meant proportional in such a way that the greater the density of the gas the slower it diffuses. For example, if the rates of diffusion were directly proportional to the densities, oxygen, being sixteen times as heavy as hydrogen, would diffuse sixteen times as fast; or if the rates of diffusion were directly proportional to the square roots of their densities, the rate of the diffusion of oxygen to that of hydrogen would be as $\sqrt{16} : \sqrt{1}$ or $4 : 1$; but since the rates are inversely proportional to the square roots of the densities, it will be evident that the rate of diffusion of hydrogen is four times as great as that of oxygen, or rate of diffusion of hydrogen : rate of diffusion of oxygen :: $\sqrt{16} : \sqrt{1}$ or :: $4 : 1$.

Graham in his experiments employed a diffusion tube. This tube was open at both ends, and varied in length from six to fourteen inches, and having a diameter of half-an-inch. A wooden plug is fitted into the tube so as to occupy the whole of the internal space except half-an-inch

at one end, and this space left unoccupied by the wooden cylinder is filled with plaster of Paris, which possesses the power of 'setting' or becoming a hard porous mass and as soon as the plaster has set the cylinder is withdrawn.

The tube is divided into volumes of capacity, filled with gas and placed over water. The rate of the rise or depression of the water is carefully noted, and the composition of the gas, both before and after the experiment is ascertained. It was by this method that Graham determined the relative diffusibility of different gases. Graham took the velocity of diffusion of air as the standard of comparison, and the density of the air as 1. This, of course, does not affect the results; for we have seen that hydrogen diffuses four times as fast as oxygen when the density of hydrogen is taken as unity, or as $\sqrt{16}$ to $\sqrt{1}$ or 4 to 1. When air is taken as the unit density the density of hydrogen is 0·06926, and that of oxygen is 1·1056.

The square root of 0·06926 or $\sqrt{0{\cdot}06926}=0{\cdot}2632$, and $1 \div 0{\cdot}2632 = 3{\cdot}7794$. Graham found experimentally that the rate of diffusion of hydrogen compared with that of air was 3·83, which agrees very closely with the result obtained by calculation.

Again, the density of oxygen is 1·1056 compared with that of air taken as the unit. Now $\sqrt{1{\cdot}1056}=1{\cdot}0515$, and the reciprocal of this or $1 \div 1{\cdot}0515 = 0{\cdot}951$. We have seen that when hydrogen is taken as the unit the rate of diffusion of hydrogen compared to that of oxygen is as 4 to 1. But $3{\cdot}83 \div 0{\cdot}9487$ (where 0·9487 is the experimental result obtained by Graham)$=4$ nearly. We thus see that whether air or hydrogen is taken as the unit the result is not affected in the least.

We now give a table of Graham's results taken from Sir H. E. Roscoe and Professor Schorlemmer's *Treatise on Chemistry*. It is scarcely necessary to state that this Treatise is so exhaustive that, when completed, it will be

the fullest and most valuable work on chemistry in the English language :—

| Gas. | Density. | Square Root of Density. | $\frac{1}{\sqrt{\text{Density}}}$ | Velocity of Diffusion of Air = 1. |
|---|---|---|---|---|
| Hydrogen, . . . | 0·6926 | 0·2632 | 3·7794 | 3·83 |
| Marsh Gas, . . . | 0·559 | 0·7476 | 1·3375 | 1·344 |
| Steam, . . . | 0·6235 | 0·7896 | 1·2664 | —— |
| Carbonic Oxide, . . | 0·9678 | 0·9837 | 1·0165 | 1·1149 |
| Nitrogen, . . . | 0·9713 | 0·9856 | 1·0147 | 1·0143 |
| Ethylene, . . . | 0·978 | 0·9889 | 1·0112 | 1·0191 |
| Nitric Oxide, . . | 1·039 | 1·0196 | 0·9808 | —— |
| Oxygen, . . . | 1·1056 | 1·0515 | 0·9510 | 0·9487 |
| Sulphuretted Hydrogen, | 1·1912 | 1·0914 | 0·9162 | 0·95 |
| Nitrous Oxide, . . | 1·527 | 1·2357 | 0·8092 | 0·82 |
| Carbon Dioxide, . . | 1·52901 | 1·2365 | 0·8087 | 0·812 |
| Sulphurous Acid, . | 2·247 | 1·4991 | 0·6671 | 0·68 |

The calculated velocities of diffusion only agree with those observed when the porous plate through which the diffusion occurs is very thin. When the plates are thick the rate of diffusion is considerably retarded by friction. It is evident that when the plate is thick the gas has to pass through a series of capillary tubes, and the passage of a gas through capillary tubes (from Latin *capillaris*, pertaining to the hair, hence very narrow or hair-like tubes) has been termed the *transpiration of the gases*, and this is not to be confounded with diffusion, but is governed by different laws. In transpiration it is the motion of a mass of gas that has to be dealt with, but in diffusion the motion is molecular, and quite distinct from that of the mass.

When the following gases were allowed to pass through capillary tubes, Graham found that the rate of transpiration of equal volumes was as follows :—

| | |
|---|---|
| Oxygen, . . | 1·00 |
| Hydrogen, . | 0·44 |
| Carbonic Oxide, | 0·72 |

From the table it will be seen that the relative rates of diffusion of these gases are represented by: oxygen, 0·9487, hydrogen, 3·83, carbonic oxide, 0·82. From these numbers it will be seen that the rates of diffusion and transpiration are altogether different.

No substance is so well adapted for exhibiting the law of diffusion as a thin plate of artificial graphite ·05 millimetre thick.

Graham obtained the times of diffusion for hydrogen, oxygen, and carbonic dioxide. He took the density of oxygen in this case as the unit of comparison.

The density of oxygen, when hydrogen is taken as the unit, is 15·96; hence, when oxygen is taken as unity, the density of hydrogen is 1÷15·96 or 0·06265, and the square root of this is 0·2502.

Again the density of carbon dioxide is 21·96÷15·96 or 1·3759, and the square root of this is 1·173.

It has been already stated that the rates of diffusion of gases are inversely proportional to the square roots of their densities, and since the times of diffusion are inversely proportional to the rates, they are directly proportional to the square roots of the densities.

Now Graham found the following times of diffusion when the gases were under a pressure of 100 millimetres of mercury :—

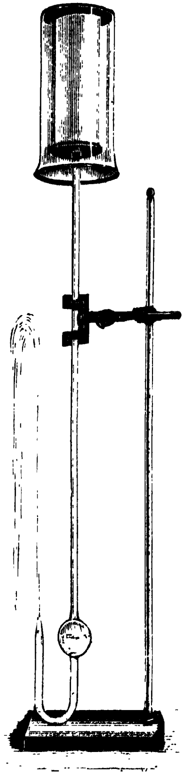
| | Time of Molecular Passage. | Square Root of Density. |
|---|---|---|
| Hydrogen, | 0·2476 | 0·2502 |
| Oxygen, | 1·000 | 1·000 |
| Carbonic Dioxide, | 1·173 | 1·1816 |

Graham allowed the same gases to diffuse into a vacuum, and obtained the following results :—

| | Time of Molecular Passage. | Square Root of Density. |
|---|---|---|
| Hydrogen, | 0·2505 | 0·2502 |
| Air, | 0·9601 | 0·9507 |
| Oxygen, | 1·000 | 1·000 |
| Carbonic Dioxide, | 1·860 | 1·173 |

It will be seen that these numbers closely correspond with those already given. The conclusion to be drawn from this is that artificial graphite does not admit the gas to pass through it in mass, or, as it is termed, by transpiration, but readily allows it to pass through when in a state of molecular or diffusive movement, and this is the case whether the gas passes under pressure into air or into a vacuum.

A plate of artificial graphite thus acts as a pneumatic sieve, which allows the passage of the molecules, and prevents the masses from passing through. It is impermeable to what may be called a current of a gas, though the molecules pass through by virtue of the diffusive property of gases.



The phenomena of diffusion may be very convincingly illustrated as follows: Take a glass tube about a metre in length, and 1 centimetre in diameter, and having a bulb blown on it.

Take one of the cylindrical porous cells of a galvanic battery, and fit a caoutchouc cork into it with an aperture for the reception of the glass tube. The other end of the tube terminates in a fine point as in the figure opposite.

Take a vessel full of hydrogen, and hold it over the porous jar. The hydrogen gas will diffuse into the porous cell more quickly than the air will issue, viz., as $\sqrt{14 \cdot 4}$ to $\sqrt{1}$ and as 3·8 volumes to 1. If, before adjusting the glass tube, coloured water is placed in the bulb, the pressure in the porous cell, owing to the

hydrogen entering it more rapidly than the air issues, will drive out some of the coloured water in the form of a fine jet.

A simple experiment which shows how gases may be separated can easily be performed.

This separation of a gas from another has been termed atmolysis (from Greek *atmos*, vapour, and *lysis*, a loosing).

A mixture of hydrogen and oxygen, in the proportion of two volumes of hydrogen to one volume of oxygen, best obtained by the electrolysis of water, is passed in a slow current through a long clay tobacco pipe, and the issuing gas collected over water. This mixture explodes violently on the application of a light. It is, however, found that when a light is applied to the gas which has passed through the pipe in a slow current no detonation takes place. If a glowing chip of wood be introduced it will immediately burst into flame. This shows that during the passage of the detonating mixture through the clay pipe, the greater part of the lighter gas has escaped by diffusion while the heavier oxygen has passed through.

### Effusion of Gases.

This is the name which Graham gave to the flow of gases under pressure through very small apertures in a metal plate. The same law which governs diffusion applies to this molecular motion of gases. The time required for equal volumes of different gases to pass through an aperture of $\frac{1}{300}$ of an inch was found to be very nearly proportional to the square roots of their densities. Bunsen has applied this law, which is true for the flow of all fluids, through a minute aperture in a plate, for determining the specific gravity of gases. This method is used with perfect success when only small quantities of a gas can be obtained.

Mention has already been made of the successful liquefaction of oxygen by Cailletet and Pictet fourteen years ago, and the subsequent liquefaction of all the so-called permanent gases.

This success verified the prediction made by Faraday in a lecture delivered at the Royal Institution, London, on January 31st, 1845, and reported in the *Times* of February 4th of that year. Faraday predicted in that lecture that all gases could be liquefied provided a sufficiently low temperature could be obtained.

What is termed the 'Faraday Lecture,' in commemoration of the late illustrious Professor Faraday of the Royal Institution, London, was delivered by Professor Dewar of Cambridge, on Friday, June 26th, 1891. A notice of this lecture appeared in the *Times* of June 30th, 1891. Professor Dewar gave a history of the successful labours of Faraday in the field of the carbon compounds. These we omit, as, though of the greatest interest, they are not directly connected with the subject of gases considered from a physical point of view. Professor Dewar's lecture at the Royal Institution has been stated by the *Times* to be of 'an epoch-making character,' in that it 'realised with brilliant success the hopes expressed by Faraday in his memorable lecture of January 31st, 1845.' Professor Dewar succeeded in producing liquid oxygen. He also expounded the doctrine, of which the experiment furnished a splendid illustration, with respect to the production of extemely low temperatures, which go to the very bases of physics, and may even throw light on the ultimate problems of metaphysics.

The lecturer began with a brief review of the different stages and developments of Faraday's labours.

Professor Dewar's references to Faraday and the account of his own experiment are reported in the *Times* as follows:

'The origin of his (Faraday's) discoveries in this respect was a suggestion of Davy's, to heat a substance known as hydrate of chlorine (*sic*), which could be kept in ice, or sealed in a glass tube. At Davy's instigation also this was heated in a sealed tube, and produced a green fluid (*liquid*) body which was recognised as liquid chlorine. At the same time were proceeding experiments in the

crystallisation of water, and the very common one of the regelation of ice, by means of which two pieces of ice would unite and freeze together again although the temperature of the air was above freezing-point. The original idea had been that pressure could do anything. But an illustrious French chemist had made the discovery that liquid carbonic acid could be solidified by a great reduction of temperature. This was shown in the theatre of the Royal Institution on May 18th, 1848, and he laid on the table some of the solid carbonic acid, which resembled snow, made by Faraday on that occasion. In the lecture which he had delivered in 1845, Faraday expressed his opinion that the reason why so many had failed in liquefying and solidifying gases was that, although they could procure the immense pressure, they could not obtain a degree of temperature sufficiently low, and in illustration he produced olefiant gas ($C_2H_4$) in a liquid state. This was the substance which is now known as ethylene. Faraday was of opinion that, though carbonic acid would give a very low temperature, nitrous oxide ($N_2O$) would give a temperature as much below carbonic acid ($CO_2$) as the latter was below that of common ice, and he expressed the hope of being able to produce liquid oxygen, and had failed, as already stated, not because his principle was wrong but from the imperfection of his instruments. The agent which Professor Dewar had used for the production of liquid oxygen was ethylene ($C_2H_4$), which was a gaseous hydrocarbon first liquefied by Faraday. Now the temperature of solid carbonic acid was —80° C., the boiling-point of nitrous oxid (laughing gas) was —90° C., but ethylene boiled at —100° C. There was great difficulty in utilising ethylene, which was produced by the liquefaction and volatilisation of carbonic acid, but out of 150 lbs. of liquid carbonic acid only about 20 lbs. of ethylene could be produced. Thus it became necessary to use the ethylene over and over again. Its temperature, *in vacuo*, went down as low as —140° C. Oxygen boiled at —180° C.,

and he hoped to produce a temperature of about —200° C., the lowest ever reached having been —210° C. Professor Dewar then achieved his experiment of producing liquid oxygen, to the great delight of his audience. For this purpose three pumps or engines were required, one air pump, one auxiliary air pump, and a compression pump. The latter was the gift to the Royal Institution of Dr. Anderson, Director-General of Ordnance, to whom and to Dr. Ludwig Mont, and his assistants, Mr. Lennox and Mr. Heath, he was largely indebted for the success of the experiment. Liquid oxygen boiled at a temperature of —180° C., and the oxygen produced recorded the temperature in the presence of Professor Dewar's hearers. Alcohol put into the oxygen was seen to become solid in a moment. The Professor gave other illustrations of liquids boiling at excessively low temperatures. The curious part in some instances being that the boiling-point was lower than the temperature of the solid body. By the researches of Andrews, Van der Vals, Clausius, Thomson, and others, very valuable and pregnant principles had been established in connection with these low temperatures.

'It had been discovered, not by experiments, but ratiocinatively, that hydrogen boiled at —250° C. It being shown that when a piece of phosphorus was put into the oxygen nothing followed, there would seem to be a complete suspension of chemical affinity altogether, and it would seem that the Lucretian theory could be verified in fact by the proof that at these abnormal temperatures matter suffered actual death. There would be an end of all the air-thermometers when the lowest point of temperature—say about 270° C.—was obtained, air, nitrogen, and even hydrogen, would all be gone. Thus we should have reached the very fundamentals of science.

'Another result by means of which this knowledge of the *minima* of temperature in the case of different bodies was possible was the ascertainment of the 'critical points,' as

they were termed, of the several bodies to which he had referred.

'The critical point, for example, of oxygen, was —115° C., and the meaning of the expression was that point of temperature to which a body must be reduced before liquefaction could be effected.'

# WATER

# WATER

IN ordinary circumstances the importance and value of water are seldom taken into consideration, for the simple reason that in most temperate regions of the globe the supply is abundant. In large cities the health of the inhabitants depends, to a great extent, on the copiousness and purity of the supply. This is so well known that no expense and trouble are, as a rule, spared to secure all the benefits which accrue from a sufficient supply of water. Pure water is as essential to the health of a community as pure air. We know that in badly drained cities, which are insufficiently supplied with water, periodic outbreaks of pestilence occur; and this is more especially the case in hot countries.

Plant-life on the globe is so much dependent on water that means are being continually devised to prevent the recurrence of famine to which India is subject, owing to the failure of the rains to supply the water needed for the crops.

This is partly accomplished by artificial irrigation. A well in the desert has always been a most welcome sight to the thirsty traveller, and the importance attached to wells is strikingly shown in the frequent references to them in Eastern literature.

The beauty of a landscape depends entirely on the presence of water; for where this is wanting we find nothing but a treeless, barren waste. Lakes and rivers, apart from their usefulness, give a character to the neighbourhood in which they occur, and enhance the

pleasure which every one derives from the varied appearance of a landscape. Notwithstanding the recognised importance of water from the earliest times, it is little more than a century since a knowledge of its composition was acquired. This is not surprising when it is borne in mind that chemistry as a science was non-existent until the time of Cavendish, Priestley, and Lavoisier.

Before this period the energies of alchemists were directed to the search for the 'philosopher's stone,' and their attention was almost entirely confined to the metals. Water was thought to be an element or simple body.

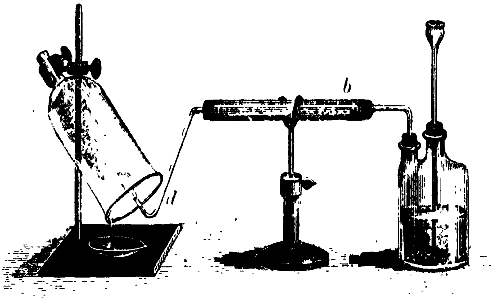
Cavendish was the first who proved that when two volumes of hydrogen are burned along with one volume of oxygen pure water and nothing else is formed. It is rather remarkable that though he knew this he did not fully understand the result at which he arrived.

This was owing to preconceived notions which at that time held sway in regard to the nature of combustion and chemical action generally. It was the great French chemist, Lavoisier, who first explained the composition of water in the year 1783. Lavoisier caused water to drop slowly into a tube which was fitted into a gun-barrel. A tube was also inserted into the other end of the barrel, and connected with what distillers term a 'worm,' or spirally-wound tube, which is immersed in cold water for the purpose of converting steam and other vapours to liquids.

The gun-barrel was heated to redness in a furnace, and the water-vapour in its passage through the barrel was partially decomposed, the oxygen uniting with the iron and forming magnetic oxide of iron, whilst the hydrogen passed through, along with the undecomposed steam. The steam was condensed in the worm, and the hydrogen that passed through was collected. From this experiment, or series of experiments of the same character, Lavoisier found that 13·13 parts by weight of hydrogen united

with 86·87 parts by weight of oxygen to form water. To find the volume from this, these numbers must be divided by the atomic weights. The atomic weight of hydrogen is 1, and that of oxygen 15·96, 13·13 volumes of hydrogen, according to these numbers, will combine with 86·87÷15·96 or 5·44 volumes of oxygen. This, as Lavoisier stated, gives 12 volumes of oxygen combining with 28·92 volumes of hydrogen. It will be seen later on that the percentage composition of water by weight is 11·136 of hydrogen and 88·864 of oxygen; or 11·136 volumes of hydrogen to 5·567 of oxygen, *i.e.* 2 volumes of hydrogen unite with 1 volume of oxygen to form water.

This last was the result arrived at by Cavendish, and confirmed by Humboldt in 1805 by more refined experiments than those of Cavendish. When hydrogen is burned in the air, water is formed. If granulated zinc




and dilute sulphuric acid are mixed in the bottle, hydrogen is generated. It is made to pass through the tube *b* containing dry chloride of calcium in order to dry the hydrogen. The hydrogen issuing from the tube *d* is lighted, and when a dry bell-jar is fixed in position over the flame, after some time drops of water will be seen trickling down from the bell-jar. Since nothing but air was present in the jar at the beginning

of the experiment, it is clear that the oxygen necessary for the combustion of the hydrogen was supplied by the air contained in the jar, and that the water formed is the result of the combustion of the hydrogen with the oxygen in the air.

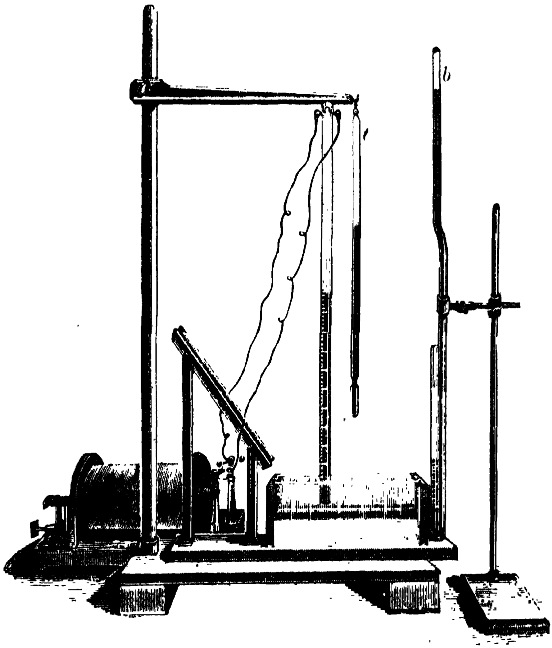
Cavendish's method of ascertaining the composition of water is in principle still employed. It is, as a matter of course, greatly improved, and consequently much more accurate than could have been possible when the method was first devised. It is much easier to improve methods, even in most important details, than to devise them. This is true of all great inventions, unless, indeed, as in the case of the steam-engine, the improvement be so great as to amount to a new invention, and render what was almost practically useless, the most practically useful invention ever given to the world, and which, combined with the telegraph, has done so much to increase the intercourse between distant countries.

The instrument employed for this purpose is termed a eudiometer (from Greek *eudios*, clear, and *metron*, measure; and *eudios* is an adjective from *eudia*, meaning fair weather). The eudiometer is also employed for determining the composition of the atmosphere, and for this reason it has doubtless been so named.

It is a strong glass tube, a metre in length, closed at the top and open at the bottom, with platinum wires sealed through the glass near the top. The diameter is 0·025 metre. A millimetre scale is etched on the glass; but however carefully the tube has been made, the capacity of each division of length on the scale will not be exactly the same. The exact capacity of each division is ascertained by a process of calibration (from French *calibre*, a bore), which consists in pouring successively the same volume of mercury into the eudiometer till it is quite full. The height to which each volume of mercury reaches is carefully read off on the millimetre scale which is etched on the glass. In beginning an experiment, a

drop of water is put into the eudiometer for the purpose of rendering the gases moist. This lessens the resistance to the passage of the electricity between the two platinum wires sealed into the tube.

The eudiometer is then completely filled with mercury and inverted in a pneumatic trough. The ordinary pressure of the atmosphere amounts to 0·760 metre of mercury, and, therefore, after the eudiometer has been inverted, there will be a part of the upper end of the tube containing nothing but some water-vapour.




The next process consists in passing a certain volume of pure oxygen up through the mercury into the tube. The oxygen is prepared from pure potassium chlorate; and as

oxygen is about eleven thousand times as light as mercury, it will, when introduced at the bottom of the tube, rapidly ascend. After the oxygen has been introduced the volume is read off, and the reductions required for temperature and pressure are made.

For the purpose of ascertaining the pressure and temperature, a barometer *b* is placed as in the figure, and a thermometer *t* is suspended near the eudiometer. The surface of the mercury in the eudiometer tube is not level, but crescent-shaped. It forms what is termed a meniscus (from Greek *meniskos*, a crescent-shaped body, the word *meniskos* being a diminutive from *mēnē*, the moon).

The level of the meniscus in the tube as well as the temperature is read off by a telescope placed in a horizontal position, and at a sufficient distance to prevent the radiation from the observer having any effect on the reading.

When the temperature and height of the mercury in the eudiometer have been ascertained, the height of the mercury in the barometer is also read off by means of the telescope. The height of the mercury in the eudiometer above the level of the mercury in the trough is then subtracted from this. The height of the mercury in the eudiometer is ascertained by reading the heights of the upper and lower levels; the lower level being the surface of the mercury in the pneumatic trough.

It is evident that the difference between the height of the mercury in the eudiometer and that in the barometer gives the pressure to which the moist oxygen gas in the eudiometer is subjected. The temperature having been ascertained, the height of the level of the column of mercury is reduced to that at which it would stand at 0° C. Another correction is needed, owing to the volume of the gas having been measured in the moist state. If the gas had been dry, and subjected to the same pressure as that under which the moist gas stands, it would have occupied a smaller volume. The pressure is equal to the tension of the gas; but the gas being moist, the tension is equal to

the tension of an equal volume of dry gas plus the tension of the water-vapour at the temperature of observation. If the tension of the water-vapour were subtracted, the pressure exerted on the dry oxygen would be less than the observed pressure by the amount of the tension of the water-vapour. If subjected to the observed pressure the volume would be less than that deduced from the readings of the scale. If, however, an additional pressure, equal to the tension of the water-vapour, is added to that observed, the volume of the moist gas will be reduced to that which the dry gas would occupy at the pressure observed.

In order to ascertain the pressure to which the observed volume of the gas would be subjected if the gas were dry, the tension of the vapour of water, ascertained from a table of tensions, must be subtracted from the observed pressure. The tension will be given in the table opposite the number which corresponds to the temperature of the gas in the eudiometer.

There are now sufficient data to enable us to find by calculation the volume of the gas at the normal temperature, viz., 0° C.; for we have—

(1) The volume ascertained by taking the readings from the upper level of the mercury and from the calibration-table of the eudiometer.

(2) The temperature of the gas has also been ascertained by means of the thermometer hung up near the eudiometer.

(3) The pressure to which the dry gas would have been subjected; this being ascertained by subtracting the tension of the vapours of water corresponding to the temperature of the gas.

The volume of the dry gas at 0° C. may be calculated under a pressure of 1 metre or 76 centimetres of mercury at 0°C. The height of the mercury column must always be reduced to that which it would possess at 0° C.

The next part of the process consists in introducing a

volume of pure dry hydrogen, and in this case care must be taken that no bubbles of the gas remain adhering to the sides of the tube. The volume of added hydrogen should be sufficiently large to ensure that the inflammable mixture of two volumes of hydrogen and one volume of oxygen shall form not more than from 30 to 40 per cent. by volume of the whole gas introduced into the eudiometer tube. The precaution is necessary to prevent the mercury from being oxidised by the high temperature of the explosion.

The more largely the detonating mixture is diluted the less likely the mercury is to be oxidised; but provided the detonating mixture form only 35 per cent. of the entire volume the mercury is not in the least liable to be chemically affected.

If five volumes of oxygen have been introduced into the eudiometer, then on the assumption that two volumes of hydrogen are needed for one volume of oxygen, to form the detonating mixture, fifteen volumes must amount to 35 per cent. of the total volume introduced into the eudiometer. To find the additional volumes of hydrogen needed for dilution; let $v$ equal the number, then $(v+15) \times \frac{35}{100}=15$, or $(v+15)\times\frac{7}{100}=3$, therefore $7v+105=300$, $v=\frac{195}{7}$, or nearly 28 volumes of hydrogen are needed for dilution. When the temperature of the mixed gases and that of the mercury in the eudiometer-tube are the same as that of the air, the volume of the mixed gases is again read off with exactly the same precautions as before, and the temperature and pressure again observed. After this, the open end of the eudiometer is pushed down below the mercury in the pneumatic trough, upon a plate of caoutchouc which has been previously moistened with a solution of perchloride of mercury (*i.e.* a compound of chlorine and mercury somewhat soluble in water and exceedingly poisonous, popularly termed corrosive sublimate, and distinguished by its solubility and virulent poisonous properties from the lower chloride of mercury termed

calomel). The tube must be firmly held by means of a clamp in this position, otherwise, when the explosion takes place, some of the mercury would be expelled from the tube through the open end, and vitiate the result. The object in moistening the caoutchouc with corrosive sublimate is to prevent injury to the mercury, and the possibility of escape from the tube owing to the heavy pressure due to the explosion. The electric spark passed through the mixed gases is obtained from an induction coil. The current of electricity obtained from the coil passes from one platinum wire through the gas to the other wire, the spark produced causes the mixed gases to explode, and thereby become united, and a flame is observed to pass down the tube. After the explosion the tube is freed from its pressure against the caoutchouc, and the mercury from the trough again enters the tube, being driven up by the pressure of the atmosphere on its surface. A considerable diminution in volume is observed. The eudiometer is then allowed to remain untouched for a period sufficiently long to allow the temperature of the gas to become the same as that of the surrounding air. This will be after a considerable period, amounting to upwards of two hours.

The volume which has disappeared is not exactly equal to that previously occupied by the gases that have combined, since the water formed occupies a very small space.

If extreme accuracy be required, it is necessary to take into account the volume which the water formed occupies, and subtract this from the contraction observed after the explosion. It is evident that when the gas within the eudiometer, after the explosion, has cooled down to the temperature of the surrounding air, the mercury in the tube will stand higher than it stood before the explosion, and the difference between the heights of the mercury before and after explosion indicates the contraction that has occurred, or what is the same thing, the volume of the gases that have combined to form water. Of course the

pressure exerted on the residual hydrogen is less than that exerted on the mixed gases before explosion.

It is absolutely necessary to read off the temperature and pressure, both before and after the explosion; for during the experiment, the pressure and temperature of the atmosphere may have considerably altered, and besides the volume of hydrogen remaining after the explosion has to be reduced to the volume it would occupy at the temperature and pressure of the mixed gases before explosion, in order to ascertain the contraction that has taken place. Now if the water formed by the explosion were withdrawn from the volume of hydrogen remaining after the explosion, the volume of the remaining gas would be increased by this amount, the pressure being supposed to be the same, and consequently the contraction would be to the same extent diminished. The exact volume therefore represented by the contraction is obtained by subtracting the volume occupied by the water from the observed contraction. Other minor corrections are needed in cases where the greatest attainable accuracy is aimed at; but these are of a somewhat complex character, and those enumerated are sufficient to give a good idea of the immense care and manipulative skill required for exact quantitative experiments. The problem now is to find out the mass of the water formed. It is not to be assumed that for every volume of oxygen that has disappeared, two volumes of hydrogen have likewise disappeared; for the object of the experiment is to ascertain the exact number of volumes of hydrogen that have combined with the known number of volumes of oxygen that were introduced. From the amount of oxygen introduced, the mass of the water formed is known from the gravimetric analysis of water, and since the mass of water formed is known, its volume is at once known. It is moreover to be remembered that the volume of water to some extent depends upon its temperature. Suppose the volume of water is formed from five volumes of oxygen, or from any number of volumes

less than those introduced into the tube, then if the volume of the water formed by the combination of five volumes of oxygen with hydrogen be known, and if the detonating mixture containing five volumes of oxygen be diluted, so that the detonating mixture forms only 35 per cent. of the whole volume, it is known what fraction of the entire volume of the mixed gases before explosion is occupied by the water formed. This fraction is a constant quantity, no matter how many volumes of oxygen are introduced, provided the detonating mixture form 35 per cent. of the total volume.

To ascertain the volume of water formed in every case, it is therefore only necessary to multiply this constant fraction by the total number of volumes of the mixed gases in the eudiometer *before* explosion. The constant fraction is 0·0007, and this, multiplied by the total bulk of the mixed gases before explosion, must be subtracted from the observed contraction.

As a result we subjoin the following:

Synthesis by volume reduced to 0° C, and 1 metre of mercury pressure.

| | |
|---|---|
| Volume of oxygen taken, . . . | 95·45 |
| Volume of oxygen and hydrogen, . | 557·26 |
| Volume after explosion, . . . | 271·06 |

The number of volumes that have disappeared therefore is 557·26−271·06 or 286·2. The number 271·06 is the number of volumes of hydrogen remaining after the explosion. To find the number of volumes of hydrogen that have disappeared, it is necessary to add the number of volumes of oxygen taken to the volumes of hydrogen that remain after the explosion, and subtract the sum from 557·26 or 271·06+95·45=366·51. Now 557·26−366·51 =190·75.

It follows that 190·75 volumes of hydrogen have disappeared. But we have seen that 95·45 volumes of oxygen have disappeared. Now 190·75÷95·45=1·9984. Hence

one volume of oxygen has combined with 1·9984 of hydrogen to form water. By very carefully repeating the above experiments the volumetric composition of water has been ascertained within a limit not exceeding $\frac{1}{10000}$ of the total volume to be in the proportion of one volume of oxygen to two volumes of hydrogen.

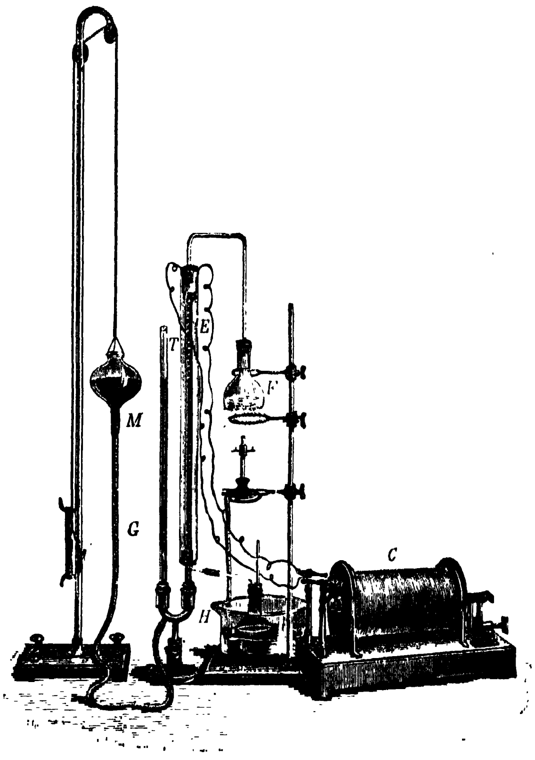
Knowing now that two volumes of hydrogen combine with one volume of oxygen to form water, it is only natural to wish to know whether any contraction has taken place; that is, if the water formed be converted into steam, to know whether the steam will occupy the same volume which was occupied by the hydrogen and oxygen before combination. The French physicist Gay-Lussac, who also determined the composition of water by volume, first proved that the three volumes of the gases that combine to form water only occupy two volumes in the form of steam. He found the specific gravity of steam to be 0·6235. It may be here stated that the specific gravity of a gas or vapour is the number which expresses the ratio of the weight of a definite volume of the gas or vapour to the weight of an equal volume of atmospheric air, at the same temperature and pressure. Steam is therefore 0·6235 as heavy as air, according to Gay-Lussac. But the specific gravity of oxygen is 1·106, and that of hydrogen is 0·069. On the assumption that the three volumes, viz., two of hydrogen and one of oxygen, that go to form water become two volumes of steam, we have $1·106+0·069\times 2=1·244$, and this divided by 2 gives 0·622, the actual specific gravity of steam, and this agrees very nearly with the experimental results of Gay-Lussac.

The actual contraction which takes place after explosion can be directly seen.

When a strong current of galvanic electricity is passed through acidulated water, the water is decomposed into oxygen and hydrogen. The apparatus used for collecting the detonating gases is termed a voltameter.

If the detonating mixture obtained by this process be

introduced into a eudiometer, arranged in such a manner that the pressure can be altered at pleasure, the actual contraction after explosion is easily observed.




*E*, eudiometer; *T*, glass tube surrounding the eudiometer; *F*, flask with amyl alcohol which is condensed, after passing through the tube, in flask cooled in trough *H*; *M*, reservoir containing mercury, which can be raised or lowered; *G* caoutchouc tube; *C*, coil.

The eudiometer into which the detonating mixture is introduced is surrounded by a glass tube, and between this tube and the eudiometer a current of the vapour of amyl alcohol is passed, and is received into a small bottle

connected with the lower end of the space between the two tubes.

Amyl alcohol boils at 132° C.; its boiling-point is therefore 32 degrees above the boiling-point of water. This ensures the rapid conversion into steam of the water formed after the explosion. After the detonating mixture in the eudiometer has acquired the temperature of 132° C., by reason of the vapour of the alcohol between the two tubes, the height of the mercury in the two branches of the eudiometer is brought to the same level by means of the reservoir containing mercury, which is connected with the iron foot of the eudiometer by a caoutchouc tube. The volume of the mixed gases is then read off, after which the pressure on the gas is reduced by lowering the level of the mercury, this being done by lowering the reservoir. An electric spark is then passed by means of an induction coil. After the combination has taken place, the level of the mercury in the two branches is again brought to the same height, and the volume read off as before, the temperature being still kept at 132° C. The volume is found to be exactly two-thirds of that occupied by the mixed gases before explosion, hence two volumes of hydrogen have united with one volume of oxygen to form two volumes of the vapour of water.

### Gravimetric Synthesis of Water.

The volumetric composition of water having been ascertained by means of the eudiometer, it is an easy matter to find its percentage composition by a simple calculation. Taking hydrogen as the unit, it has been ascertained that oxygen is 15·96 times as heavy as hydrogen, hence two volumes of hydrogen weigh 2, and 1 volume of oxygen 15·96, and 17·96 parts by weight of water contain two parts by weight of hydrogen, hence 100 parts by weight of water contain $\frac{2}{17 \cdot 96} \times 100$ or 11·136.

The percentage composition of water by weight is therefore, hydrogen 11·136, oxygen 88·864 by calculation. It

is, however, of so great importance to test these numbers by direct experiments that this has been very carefully done. The immense importance of water in the economy of nature naturally excites the desire to possess as complete a knowledge of its composition and properties as it is possible to acquire. The principle adopted for ascertaining the composition of water by weight is exceedingly simple, the difficulty being to arrange matters so that the smallest possible errors may occur in the application of the principle for the purpose in view. The principle depends on the fact that many of the oxides of metals, when heated in a current of hydrogen, lose their oxygen, which combines with the hydrogen to form water. For the purpose of the gravimetric synthesis of water, copper oxide is found to be most suitable.

It is only necessary to ascertain the loss of weight of the copper oxide, and the weight of the water formed, in order to possess all the data required for the calculation of the percentage composition of water by weight, for pure water is composed of nothing else but oxygen and hydrogen.

The first to propose and carry out the method of determining the synthesis of water were Berzelius and Dulong in 1820.

The results they obtained were as follows:—

| Experimenting Number | Loss by weight of oxide of copper. | Weight of water formed. |
|---|---|---|
| 1 | 8·051 | 9·052 |
| 2 | 10·832 | 12·197 |
| 3 | 8·246 | 9·270 |

From these numbers we get the percentage composition of water by weight.

For 9·052 parts by weight of water contain 8·051 by weight of oxygen, therefore a hundred parts by weight of water contain $\frac{8\cdot051}{9\cdot052} \times 100$, or 88·942; this subtracted from 100 gives the weight of hydrogen in a hundred parts of water.

| | Experiment. 1 | Experiment. 2 | Experiment. 3 | Mean. |
|---|---|---|---|---|
| Oxygen, | 88·942 | 88·809 | 88·954 | 88·90 |
| Hydrogen, | 11·058 | 11·191 | 11·046 | 11·10 |
| | 100·000 | 100·000 | 100·000 | 100·00 |

Although the mean of these numbers agrees pretty well with the results arrived at by calculation, the separate experiments show considerable variation, and do not therefore give us certain information as to the exact proportion in which the gases combine by weight to form water. These experiments were very carefully repeated by Dumas and Stas in the year 1843, and they pointed out the most probable sources of error in the experiments of Berzelius:

In the first place, the weight of the water formed ought either to be ascertained *in vacuo* or reduced to a vacuum; by this the weight of the water formed is increased from 4 to 12 milligrammes.

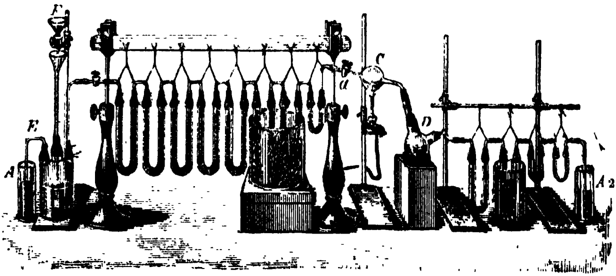
2. The weight of the oxygen must also be reduced to vacuum; that is to say the weight of the copper oxide must be so reduced, and the weight of the copper after it has yielded up its oxygen to the hydrogen. The weight of the copper oxide could be ascertained by weighing it in a vacuous bulb of known volume, and the weight of the reduced copper can be ascertained by exhausting the bulb *C* after the experiment. The volume of *C* is of course known. The weight of the bulbs plus their contents is ascertained by subtracting the weight of the air corresponding to the difference of the volume of air displaced by the weights and the bulbs.

3. Berzelius and Dulong did not dry the hydrogen sufficiently.

4. Berzelius did not make his experiments on a sufficiently large scale, even supposing he had dried the hydrogen sufficiently and made the proper reductions for weight. The larger the scale in which quantitative ex-

periments are carried on, the less are the results affected by experimental errors.

In the figure, *E* is the bottle in which hydrogen is generated. *F* is a funnel supplied with a stop-cock, and



containing sulphuric acid. *A* contains mercury into which a tube connected with the generating bottle dips. This tube acts as a safety valve.

The first U-tube contains broken pieces of glass moistened with nitrate of lead.

The second U-tube contains glass moistened with sulphate of silver.

The third U-tube contains, in the limb nearest the generating bottle, pumice moistened with sulphuric acid, and the other limb contains pieces of solid caustic potash.

The fourth and fifth U-tubes are filled with solid caustic potash, in coarse pieces in order to allow the hydrogen to pass.

The sixth and seventh U-tubes contain fragments of pumice powdered over with phosphorous pentoxide, which is remarkably hygroscopic, and therefore valuable for drying gases. These two U-tubes, viz., sixth and seventh, are kept at a very low temperature by means of a freezing mixture in which they are immersed.

The eighth is a small tube containing phosphorous pentoxide. This small tube has been carefully weighed.

*C* is a bulb blown on hard glass in order to be able to stand the heat applied without melting. It contains copper oxide, and is provided with a stop-cock *a* at the

upper end, and is drawn out at the lower end so that it may be inserted into the narrow neck of the bulb *D* which receives the water. The bulb *C* is heated by means of a Bunsen lamp which is supported on a sliding ring or holder of a retort-stand.

The U-tube placed next the bulb *D* contains pieces of fused caustic potash.

The next U-tube contains phosphorous pentoxide, and is surrounded by a freezing mixture, and next to this a small weighed tube is placed containing phosphorous pentoxide, whilst the tube at the end is not weighed.

Finally, a cylinder $A_2$ filled with oil of vitriol, through which the excess of hydrogen passes, completes the arrangement of the apparatus.

No less than nineteen separate experiments with this apparatus were made by Dumas, and they were carried out with the greatest skill and precaution.

It is exceedingly difficult to procure absolutely pure hydrogen from the action of sulphuric acid on zinc. The zinc is rarely quite pure, and the sulphuric acid may contain oxides of nitrogen and other impurities. This is the reason that when chemists employ zinc and sulphuric acid, for the detection of arsenic in cases of supposed poisoning, so great care has to be taken in order to ascertain whether the materials are pure before the suspected liquid is added.

The impurities which the hydrogen, evolved from the zinc and dilute sulphuric acid, may contain are dioxide of sulphur (used in the preparation of sulphuric acid), oxides of nitrogen (also used in the preparation of sulphuric acid), arseniuretted hydrogen (arsenic being present as an impurity in the zinc), and sulphuretted hydrogen (from the reduction of the sulphuric acid).

The materials in the U-tubes completely eliminate any of these impurities that may be present. Sulphuretted hydrogen is completely absorbed by the lead nitrate, the sulphur combining with the lead to form a sulphide; the silver sulphate decomposes the arseniuretted hydrogen,

the arsenic combining with the silver and the hydrogen with the sulphuric acid. The other tubes are for the absorption of any carbonic acid that may be present in the hydrogen. It would be completely absorbed in passing through the tubes containing caustic potash. Pumice moistened with sulphuric acid is a powerful desiccant as well as phosphorous pentoxide. The U-tubes containing the substances will completely dry the gas in its passage through them. In order to make sure that the gas passing through the stop-cock of the bulb is perfectly dry, the small tube next the bulb is weighed both before and after the experiment, and if there is no increase in weight it is clear that the gas that enters the bulb has been properly dried.

The small weighed tube at the end of the apparatus is also for the purpose of ascertaining whether the gas is thoroughly dry. The oxide of copper must be thoroughly dry before being introduced into the bulb *C*, for oxide of copper being hygroscopic absorbs moisture from the atmosphere. The bulb containing the oxide of copper is accurately weighed, *i.e.* its weight is ascertained *in vacuo*. After all the air has been driven out of the U-tubes by a current of hydrogen, the bulb containing the oxide of copper is fixed in its place. The bulb for receiving the water formed by the action of the hydrogen on the copper oxide is also carefully weighed, before the reduction of the oxide begins, as well as the three drying tubes beyond this bulb, which absorb whatever aqueous vapour is carried forward by the hydrogen from the bulb containing the water. After the current of hydrogen has swept out every trace of air from the apparatus, the oxide of copper is heated, and the formation of water at once begins. The process is continued for from ten to twelve hours uninterruptedly. Heat is then withdrawn, and the bulb *C* is left to cool in a current of hydrogen. After the bulb has cooled the apparatus is taken to pieces, and the gas contained in the bulb is withdrawn to render it vacuous, the bulb being then weighed;

and before the bulb and tubes containing water are weighed the hydrogen is driven out by a current of air. If the weighed tubes which have absorbed the moisture carried forward by the hydrogen were weighed a second time containing hydrogen instead of air, the difference would not give the weight of the water absorbed, since hydrogen is more than fourteen times as light as air.

The difference between the weight of the bulb *D* before and after the experiment would not give the correct weight of the water which it contains. It is necessary to ascertain the volume of the water, and add to the difference of the two weighings the weight of a volume of air equal to that of the water.

The end unweighed tube is for the purpose of absorbing any moisture that might enter the apparatus before the commencement of the experiment.

It will be seen that the weight of the hydrogen is not directly determined by this process, but is deduced from the difference of the weight of the water formed; and that of the oxygen is determined from the loss of weight of the oxide of copper.

It is important to remember that no experiment can be altogether free from errors, but experimental errors are tolerably constant; that is, there is very little variation in their amount. Now when small quantities of a substance are taken, the constant experimental error has a considerable effect on the result. It is for this reason that in the determination of the atomic weights of some of the elements large quantities are operated on. The percentage experimental error may be positive or negative. It is evident that the larger the mass of water formed the less is the result affected by the experimental error. Now, had the weight of hydrogen been directly determined, the percentage experimental error on a given weight of water would represent a much greater amount on the lighter hydrogen.

Dumas in his classical experiments took as rule a weight

of oxide of copper sufficient to produce fifty grammes of water, and found that the experimental error on hydrogen, taken as the unit, was reduced to 0·005 of its weight.

In nineteen elaborate experiments, Dumas found that 840·161 grammes of oxygen were consumed in order to produce 945·43 grammes of water. It is easy from these numbers to calculate the percentage composition of water by weight; for $840{\cdot}161 \times 100 \div 945{\cdot}48 = 88{\cdot}864$. The percentage composition of water by weight is therefore,

| | |
|---|---|
| Oxygen, | 88·864 |
| Hydrogen, | 11·136 |
| | 100·000 |

Now $11{\cdot}136 \div 5{\cdot}568 = 2$ and $88{\cdot}864 \div 5{\cdot}568 = 15{\cdot}95977$, or two parts by weight of hydrogen unite with 15·95977 parts by weight of oxygen to form water—a result which agrees exactly with that obtained by volumetric analysis.

In experimenting with the detonating mixture of hydrogen and oxygen, care must be taken to avoid serious accidents. If a strong soda-water bottle is two-thirds filled with hydrogen and one-third with oxygen, and after the gases have been allowed to mix, a cork is loosely inserted in the neck of the bottle, and the bottle then held in a horizontal position, with the cork close to the flame of a candle, a loud explosion will occur, and the cork will be ejected with great force. It is better to surround the hand holding the bottle with a piece of cloth; and since the explosion may only take place after some time, the bottle must be kept with the cork close to the flame until the gases are ignited.

If a bulb capable of containing about 100 cubic centimetres, blown on a glass tube, is filled with the gas evolved by a voltameter, and after it has been filled is placed over a perforated cork containing two insulated wires connected at the ends by a fine platinum wire, it may be safely exploded as follows: The bulb is surrounded with a covering of wire gauze, and

a current of electricity is then passed through the wires. The thin platinum wire connecting the two wires which pass through the cork soon becomes red-hot, and the mixture by this means is ignited. An explosion then takes place and the bulb is reduced to powder. It is an easy matter to calculate the amount of energy thus generated by measuring the quantity of heat produced. It is known that one gramme or 11·17 litres of hydrogen at the normal temperature and pressure involves 34,462 thermal units, that is, enough heat to raise 34,462 grammes of water from 0° to 1°. But the mechanical equivalent of heat expressed in the centimetre-gramme system is 423; or, what amounts to the same thing, a mass of 423 grammes falling through a metre in height is capable of involving heat sufficient to raise one gramme of water from 0° to 1°. A thermal unit is the amount of heat needed to raise one gramme of water from 0° to 1°, and since 423 grammes falling through a metre is the mechanical equivalent of this, the amount of energy derived from burning a gramme of hydrogen is $34,462 \times 423 = 14,567,426$ grammes, or 14567·426 kilogrammes falling through the space of one metre.

It is quite possible to arrange matters so that the gases may be made to combine slowly without the slightest explosion. In order that the gases may combine rapidly high temperature is requisite, and the presence of platinum and certain other bodies as well as the passage of an electric spark causes the gases to combine rapidly. It matters not how large the mass of the detonating mixture may be, the smallest electric spark suffices to bring about an explosive combination, for the particles through which the spark passes cause the combination of the adjacent particles, and so on throughout the whole mass. No combination can occur until what is termed the temperature of ignition is reached. This differs for each gas and is perfectly definite. If the explosive mixture be diluted by gases which take no active part in the explosion, the dilution may be so great that it is

impossible to ignite the detonating mixture. This is owing to the temperature being lowered; for the spark would expend its heat in raising not only the temperature of the oxygen and hydrogen, but also that of the inactive gases.

The temperature of ignition may be termed a maximum temperature; for when the temperature is reached the gases combine, and no higher temperature than this can be attained without an immediate combination taking place.

Bunsen has determined the minimum amount of dilution by different gases needed to prevent the detonating mixture from being inflamed. When one volume of detonating gas is mixed with 2·82 volumes of carbonic acid gas, or with 3·37 volumes of hydrogen, or 9·35 volumes of oxygen, it explodes; but when mixed either with 2·89 volumes of carbonic acid gas, or with 3·89 volumes of hydrogen, or 10·68 volumes of oxygen, no explosion occurs when the electric spark passes.

It has been ascertained from these experiments that when the detonating gas is mixed with carbonic acid gas, as above, no explosion can take place unless the temperature exceeds 1790·6°, or at this temperature the mixture of carbonic acid gas and the detonating gas ceases to be explosive.

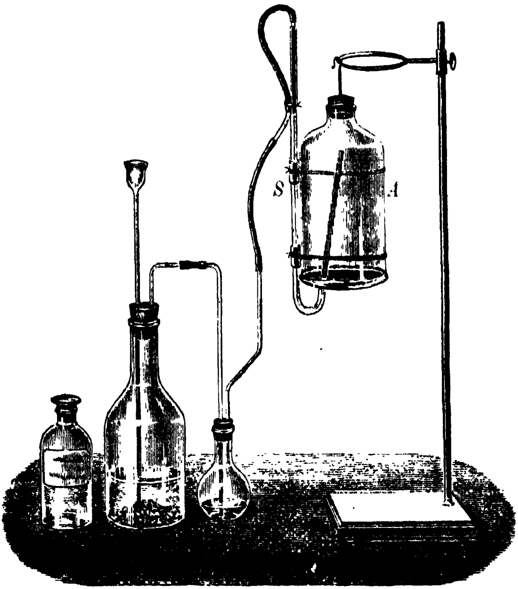
When mixed with hydrogen, as above, the mixture ceases to be explosive at 2116·8°; and when mixed with oxygen, as above, the explosion ceases at a temperature of 857·3°.

Bunsen shows that these differences in the action of the gases added to the detonating mixture are not due to the difference of the specific heats of the admixtures, or to the respective difference of their conditions or emissive power for heat, but must be ascribed to the fact that not only do these molecules which take an active part in the combination exert an influence on the reaction, but those also which are present though not directly engaged in the chemical change.

It is only when hydrogen and air are mixed in a definite proportion that the mixture becomes inflammable. The

same holds in regard to other gases. Coal gas, for instance, forms an explosive mixture with the air when a definite proportion between the air and gas has been reached, otherwise no explosion can occur.

The following experiment, taken from Roscoe and Schorlemmer's *Treatise on Chemistry*, shows very strikingly that a mixture of air and hydrogen becomes inflammable only when a definite proportion between the air and hydrogen has been reached:—




A glass jar *A* is suspended, closed at the top and a sheet of paper is gummed on the glass so as to close the mouth. A glass siphon *S* is fastened by copper wires to the glass jar, and passed through the paper which closes the mouth of the jar, the long limb of the siphon being outside. Hydrogen is generated by means of granulated zinc and dilute-sulphuric acid, and passes through some water in the small bottle in order to free it from the acid.

It passes up a glass tube, which is connected with the siphon *S* by a piece of caoutchouc tubing. A rapid current of hydrogen is generated and passes through the siphon into the glass jar. The air is driven out of the jar through the porous paper. After the jar is full of hydrogen the vulcanised tube (*i.e.* a preparation of caoutchouc and sulphur) is withdrawn from the long limb of the siphon, and the hydrogen lighted. The hydrogen being much lighter than the air can be siphoned upwards, just as water can be siphoned downwards. The hydrogen will burn quietly for some time, but it is not long before the flame begins to flicker, and begins to emit a musical note, soon accompanied by beats, or distinct and separate sounds. The air meanwhile has been entering through the pores of the paper; and when the exact proportion of air and hydrogen necessary to form an explosive mixture exists in the jar, the flame passes down the siphon, and the oxygen of the air which has entered the jar unites with the hydrogen, accompanied by a loud explosion.

Bunsen has determined the rate of propagation of ignition in the explosive mixture of oxygen and hydrogen to be 34 metres or 112 feet per second, or about 75 miles an hour.

A simple experiment can easily be performed to show the effect of platinum in causing combination to take place between certain gases. If a spiral of clean platinum wire be held for a very short time in the flame of a Bunsen burner, and the flame be then rapidly extinguished, and the gas immediately after be allowed to stream out round the platinum spiral, the spiral soon becomes red-hot and continues to glow as long as it is surrounded by the gas, and the temperature of the spiral may rise high enough to ignite the gas. A spiral of palladium has the same effect, though spirals of gold, iron, copper, silver, and zinc, have no effect. Faraday found that a clean surface of platinum at first brings about a slow combination of oxygen and hydrogen, which after a time becomes explosive.

Finely divided platinum, termed spongy platinum, causes hydrogen and oxygen to combine at the ordinary temperature, slowly at first, but after a time, when the metal becomes hot, an explosion takes place. If the spongy platinum be held in a current of ammonia gas, it loses its power of effecting a combination of oxygen and hydrogen. This power may be regained by holding the spongy platinum in the flame of a Bunsen burner. Some other absorbable gases have the same effect on spongy platinum as ammonia.

The platinum is supposed to have the power of condensing a film of oxygen and hydrogen on its surface. This condensation brings the gases into more intimate contact, and under these circumstances they are able to combine at the ordinary temperature of the air; but heat is involved when chemical combination occurs, and this heat causes the remaining gaseous mixture, or that not condensed on the surface of the platinum, to combine.

When a jet of the detonating mixture, consisting of two volumes of hydrogen to one of oxygen is burned, the temperature of the flame is exceedingly high.

The flame is termed the oxyhydrogen flame. The flame burns from a platinum nozzle, and is of very feeble luminosity, but according to Bunsen possesses a temperature of 2844°. A watch-spring held in the flame burns, emitting at the same time a shower of sparks. The temperature of the flame is high enough to melt and even boil platinum, a metal most difficult to melt, and by means of the flame it is easy to distil silver.

To prevent the danger arising from explosion, the only really safe plan is to keep the oxygen and hydrogen in separate gasholders. If the two gases were kept in one gasholder the flame might go back through the tube and cause a disastrous explosion. The hydrogen is first lighted, and a jet of oxygen from a different gasholder from that containing the hydrogen is made to mix with the burning jet of hydrogen near the nozzle. By this arrange-

ment all danger of explosion is completely eliminated, for the hydrogen does not support combustion, but extinguishes a flame when plunged into a vessel containing it.

When an infusible solid is held in the oxyhydrogen flame, its surface is raised to a white heat, and an intense light is emitted. A cylinder of lime is generally used for this purpose, and is termed the 'lime light' or Drummond light. This light is frequently used for the purpose of throwing magnified photographs on screens for lecture illustrations and similar purposes.

In the preparation of platinum and platinum dishes, etc., the high temperature of the oxyhydrogen flame is often utilised.

For this purpose various forms of furnaces are constructed, the material used for the furnace being very carefully burned quick-lime. The furnace may consist of an upper and lower block of quick-lime, each containing a hemispherical hollow, which form together a spherical hollow for the reception of the platinum. The nozzle from which the gases issue, which, when kindled, produce the high temperature, passes through an opening in the upper block.

Messrs. Johnson, Matthey, & Co. of Hatton Garden, London, by means of the oxyhydrogen furnace, melted a mass of pure platinum weighing 100 kilogrammes, or nearly two hundredweight, and two-and-a-half times as much of the platinum alloy, consisting of platinum and iridium. The mass of melted platinum was shown, as far back as 1862, at an International Exhibition in London.

Having now given an account of the methods employed for ascertaining the composition of water, and having given some idea of the immense care and skill which have been devoted to this most important and most interesting investigation, it will be necessary, seeing that the composition of water has been completely determined, to give some details regarding its properties.

### Properties of Water.

Pure water is a clear liquid, without taste, and, when seen in moderate amount, is colourless. When viewed in considerable amount or bulk, water possesses a bluish-green colour, which may be observed in certain springs in Iceland which are due to glacier currents. If a column of distilled water, about twenty feet in length, contained in a tube with blackened sides, and ends of plate glass, be so arranged that a bright white object can be viewed through the column, the bluish-green colour of the water is distinctly visible. The colours which are usually seen in certain streams are of course the result of impurities, and are not to be reckoned as properties of pure water.

We have seen how compressible gaseous fluids are, and in this respect such a liquid fluid as water stands in striking contrast, for if a million cubic millimetres, under the pressure of one atmosphere, be subjected to a pressure of two atmospheres, the contraction experienced only amounts to fifty millimetres, whereas in the case of a gas the contraction would have amounted to 500,000 millimetres.

Water is also a very bad conductor of heat. The upper portion of a column of water little over two feet in length may be made to boil before the heat has arrived by conduction at the other end of the tube. One end may have unmelted ice in the water while the other end is boiling.

It must be remembered that when water is boiled in a pot or kettle it is not heated by conduction, but by what is termed convection. The heated particles next the bottom rise to the top, while colder particles take their place to be heated, and then rise to the top; but the heated particles on their way to the top give up part of their heat to the colder particles. It is for this reason that water is so much sooner heated than would be possible by conduction. There would in the latter case be an immense consumption of fuel needed for culinary purposes alone.

Water is also a bad conductor of electricity; indeed it is

doubtful whether absolutely pure water is capable of conducting electricity at all.

Water, like most other substances, expands when heated; but it is a remarkable property of water that if it is just near 0°C. or freezing-point, and heat is then applied, the water actually contracts until the temperature has nearly reached 4° C., when it begins to expand. It will thus be seen that above 4° C. water follows the ordinary law of expanding when heated and contracting when cooled. This is expressed by saying that the point of maximum density of water is 4° C., or according to Joule 3·945°. By this is meant that a given volume of water, say a cubic centimetre, weighs more at a temperature of 3·945 than it does at any temperature either below or above 3·945°.

As a matter of course the contraction which takes place when water is heated from zero to 3·945 is small, still it has a most important effect on the climate of temperate regions of the globe. In such a climate as that of Great Britain and the greater part of Europe, frosts frequently prevail for more or less extended periods during the winter months, and the fresh water lakes are often covered with a coating of ice more or less thick depending on the duration and severity of the frost. During frost, the water at the surface of a lake is cooled. Suppose the temperature of the water of a lake at the commencement of a frost is at 10° C., as it cools below 10° it contracts, and consequently increases in density. The colder water at the surface being thus heavier than the rest of the water in the lake sinks, and the water beneath comes to the surface. This process goes on until all the water in the lake has acquired the temperature of 3·945°, or, as is usually stated, 4°. After this, any further cooling of the water on the surface of the lake will cause it to expand. It will, therefore, be lighter than the water beneath, and will no longer sink. The surface water will in fact be frozen while the water beneath remains at 4° C.

If water had continued to contract until it reached the

freezing-point, the cold water on the surface would have continued to sink until the temperature of the whole mass had reached the freezing-point; the consequence would have been that the lakes and rivers of temperate regions would have been converted into a solid mass of ice which the summer sun would have failed to melt, and such a country as Great Britain would have become Arctic in the character of its climate. When water is freezing, as will afterwards be seen, it emits a definite quantity of heat; and since the same quantity must be absorbed before the ice is liquefied, it is certain that if our lakes were frozen into a solid mass the heat derived from the sun during the summer would be insufficient to liquefy the ice.

In Great Britain and other so-called temperate countries, deep lakes are not frozen. The frost does not last long enough to reduce the temperature of a mass of water of great depth to a temperature of 4° C., and therefore the surface water continues to sink before it reaches this temperature, and the water remains liquid.

The maximum density of sea-water is lower than that of fresh, and the freezing-point of sea-water is also considerably lower than that of fresh water. It in fact depends on the saltness of the water; but the freezing-point of sea-water is also below its point of maximum density, and therefore sea-water does not freeze *en masse*; for owing to its great depth it can never be all cooled to the point of maximum density; of course the shallower water near the shore or shallow straits in Arctic and Antarctic regions is frozen owing to the diminished power of the sun's heat in far north or far south latitudes. We therefore read of ships being 'ice-bound' in the Arctic and Antarctic regions.

Depretz has experimentally ascertained the specific gravity of water from 0° to 100°.

This is of such importance that we give the results in tabular form. It will be seen to what amount water expands from 4° down to zero or freezing-point, as well as from 4° to 100° or boiling-point. The unit volume taken

at 4°, or maximum density, has the same weight at all temperatures. If the specific gravity of water at 4° is 1, knowing the volume from zero to boiling-point, it is easy to calculate the specific gravity. The unit volume at 4° becomes 1·0001269 at 0°; let $s$ denote the specific gravity of water at 0°, then, $1{\cdot}0001269 \times s = 1 \times 1$ or $s = 1 \div 1{\cdot}000126$ $= 0{\cdot}999873$.

It is thus simply a matter of calculation to find the specific gravity of water at any temperature at which it remains liquid when the amount of expansion is known.

| Temperature. Degrees. | Volume. | Specific Gravity. | Temperature. Degrees. | Volume. | Specific Gravity. |
|---|---|---|---|---|---|
| 0 | 1·0001269 | 0·999873 | 19 | 1·00158 | 0·998422 |
| 1 | 1·0000730 | 0·999927 | 20 | 1·00179 | 0·998213 |
| 2 | 1·0000331 | 0·999966 | 21 | 1·00200 | 0·998004 |
| 3 | 1·0000083 | 0·999999 | 22 | 1·00222 | 0·997784 |
| 4 | 1·0000000 | 1·000000 | 23 | 1·00244 | 0·997566 |
| 5 | 1·0000082 | 0·999999 | 24 | 1·00271 | 0·997297 |
| 6 | 1·0000309 | 0·999969 | 25 | 1·00293 | 0·997078 |
| 7 | 1·0000708 | 0·999929 | 26 | 1·00321 | 0·996800 |
| 8 | 1·0001216 | 0·999878 | 27 | 1·00345 | 0·996562 |
| 9 | 1·0001879 | 0·999812 | 28 | 1·00374 | 0·996274 |
| 10 | 1·0002684 | 0·999731 | 29 | 1·00403 | 0·995986 |
| 11 | 1·0003598 | 0·999640 | 30 | 1·00433 | 0·995688 |
| 12 | 1·0004724 | 0·999527 | 40 | 1·00773 | 0·992329 |
| 13 | 1·0005862 | 0·999414 | 50 | 1·01205 | 0·988093 |
| 14 | 1·0007146 | 0·999285 | 60 | 1·01698 | 0·983303 |
| 15 | 1·0008751 | 0·999125 | 70 | 1·02255 | 0·977947 |
| 16 | 1·0010215 | 0·998979 | 80 | 1·02885 | 0·971959 |
| 17 | 1·0012067 | 0·998794 | 90 | 1·03566 | 0·965567 |
| 18 | 1·0013900 | 0·998612 | 100 | 1·04315 | 0·858630 |

### Latent Heat of Water.

By latent heat is meant the quantity of heat needed to change a substance from one condition to another without altering the temperature of the substance.

Suppose a kilogramme of water is taken at 0°C. and mixed with a kilogramme of water at 79°C., the mixture will be at a temperature of 39·5°, or the mean. The case will be different if a kilogramme of water at 79° is poured

into a vessel containing a kilogramme of ice at 0° ; for if the loss of heat by radiation or conduction is prevented as far as possible, it will be found that the temperature of the water is no longer the mean, but zero; or all the 79° of heat which have disappeared have just been sufficient to melt the ice. If a gramme of ice and a gramme of water, or a pound of ice and a pound of water, are taken under the same condition of temperature, the result will be the same.

It will thus be seen that a given weight of water in the state of ice, when passing from the solid to the liquid condition, takes up as much heat as would be sufficient to raise the same weight of water in the liquid state through 79°. This is termed the 'latent heat' of water. The truth is, the heat is not strictly speaking latent, but is spent in doing work. The quantity of heat required to raise a kilogramme of water through 1° is termed a thermal unit. If a gramme or pound be taken, the thermal unit would be the quantity of heat needed to raise the gramme or pound 1°.

When water freezes the quantity of heat required to keep it in the liquid state become sensible. A kilogramme of water on becoming solid gives out seventy-nine thermal units.

The property of rendering heat latent when passing from the solid to the liquid state, and evolving heat when passing from the liquid to the solid condition, is not a peculiar property of water, but is common to all substances.

This can be easily shown by means of a hot solution of acetate of soda containing as much of the acetate as can be dissolved. If this be allowed to cool, while it remains undisturbed it remains liquid, but when moved it begins to crystallise, and soon forms a solid mass. If a thermometer be put into the mass during the process of solidification a rapid rise in temperature will be observed.

It is necessary to state that though the temperature at which water freezes under ordinary conditions is 0°, it is possible for water, under certain conditions, to remain

liquid at temperatures considerably below this point. This was known to Fahrenheit as far back as 1714.

If water is boiled in a clean glass flask, and after being boiled for some time, the neck of the bottle is plugged with cotton wool while the bottle is still hot, the water within the bottle may then be cooled to —9° C. without freezing. When the cotton wool is taken out, particles of dust then enter and bring about crystallisation. The water is frozen and its temperature suddenly rises from —9° to 0°.

It has been demonstrated by Sorby that water in very small tubes can remain liquid at a temperature of −15° C.; and what is still more remarkable, Boussingault has kept water enclosed in a steel cylinder for some days at a temperature as low as —24° C. without solidification taking place.

It is also to be remembered that the melting-point of ice is affected by pressure.

At the ordinary atmospheric pressure the melting-point of ice is 0° C. Pressure, as was predicted by Professor James Thomson, of Glasgow, and after verified by Sir W. Thomson, lowers the melting-point of ice; for example, under a pressure of 8·1 atmospheres ice melts at —0·059°, and when subjected to a pressure of 16·8 atmospheres the melting-point is —0·129°. It will be sufficiently evident that if the pressure be still further increased the melting-point will be still further lowered, and it has been shown by Mousson that under a pressure of 13,000 atmospheres ice is converted into water at a temperature of —18° C. All substances which, like water, expand when solidifying have their melting-points lowered by increase of pressure. On the other hand, substances which contract when solidifying have their melting-points raised by increase of pressure.

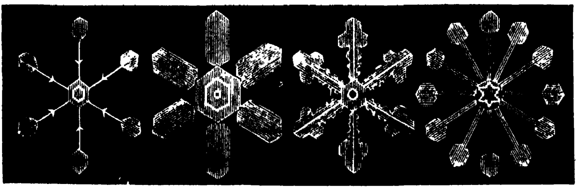
The raising of the temperature of the melting-points of paraffin and sulphur by increase of pressure is due to the fact that these bodies contract when undergoing solidification.

It is known that when two pieces of ice are rubbed together the ice at the surfaces of contact begins to melt,

and the water thus produced runs away. The melting is the result of the increased pressure; for, of course, whilst the two pieces of ice are being rubbed together they are pressed together at the same time. This increase of pressure lowers the melting-point of the ice, and the water thus formed is at a temperature below zero. When the rubbing ceases, and the excess of pressure is consequently removed, the surfaces of contact being below zero will freeze together, and the two pieces will form one solid block of ice.

This phenomenon is termed *regelation*, and was first noticed by Faraday in the year 1850. Ice crystals are hexagonal, or six-angled, the form being that of a rhombohedron.

The hexagonal form can be well seen in snow crystals. These crystals are usually compound, consisting of crystals that have grown on to another crystal in the direction of the three axes which are in the same plane, as may be seen in the following illustration :—



Ice when seen in small quantities has apparently no colour, though large masses of ice, such as icebergs, are of a deep blue colour.

When ice is rubbed it becomes electrical, but does not conduct electricity, and like water is a bad conductor of heat.

When water freezes it expands about one-eleventh of its bulk. It is owing to this property that ice floats on water. The specific gravity of ice at 0° is 0·91674. To find therefore what one volume of water at 0° becomes when it becomes ice at the same temperature, we have $v \times 0{\cdot}91674 = 1 \times 1$, or $v = 1{\cdot}09082$; or one volume of water becomes 1·09082 volumes of ice.

The force of expansion when water is solidifying is enormous. In temperate climates, such as that of Great Britain, there are during the winter not unfrequently protracted and severe frosts. On these occasions, unless the water pipes are well protected, or contain no water, they are often burst owing to the water which they contain being frozen. This bursting is often attributed to the thaw which succeeds the frost, though the damage is entirely owing to the expansive force of the water during the process of solidification, and it is only after the thaw that the cracks in the pipes make themselves manifest.

This property of water exerts a remarkable effect on rocks; for the water which has found its way into cracks in the rocks expands when frozen and splits the rock into fragments.

Bombs of thick cast-iron filled with water, and having their apertures closed by closely-fitting screws, when exposed to the severe winter frosts of such countries as Canada, are split by the expansive force of the freezing water with which they are filled.

When salt water, such as sea-water, is frozen the greater part of the salt remains unfrozen; but the ice, contrary to what is often asserted, is not quite free from salt; for it has been shown by Buchanan recently that the ice from sea-water does not contain common salt as brine which has been enclosed during the process of solidification, but the salt is frozen in crystals, and sea-water ice is a mixture of ice and salt crystals.

When ice crystals which were formed in the sea were analysed after being dried, the chlorine found in them amounted to 1·578 grammes per litre. These crystals melted at 1·3°, and not at 0°, as is the case with ice consisting of pure water.

We now come to another state in which water may exist, namely, steam. It has been mentioned that when ice is converted into a liquid a quantity of heat disappears as heat; and when liquid water is converted into gaseous

water or steam a quantity of heat also disappears as heat or becomes latent.

### The Latent Heat of Steam.

At a pressure of 76 centimetres, water in a metal vessel boils at 100° C.

The temperature of the steam given off from boiling water is the same as that of the water. The temperature ceases to rise after the water has begun to boil, and if the pressure of the air does not change, the temperature will remain constant until the whole water has 'boiled away' or become steam. The heat supplied is spent as work, or in converting the water from a liquid to a gas. The heat needed to convert the water into steam and keep it as such is termed the *latent heat of steam.*

Water needs more heat for its gaseous state than for its liquid.

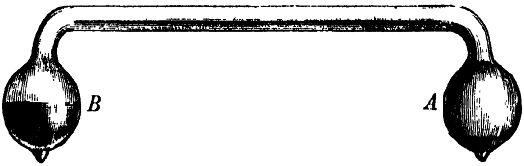
It is easy to get a rough measurement of the latent heat of steam as follows: If a jet of steam at 100° is passed into a kilogramme of water at 0° until the water boils, it will then be found that the whole weighs 1·187 kilogrammes. From this we see that 0·187 kilogramme of steam raises a kilogramme of water from 0° to 100°. Now since 0·187 kilogramme of steam raises one kilogramme of water 100°, how many kilogrammes of water would one kilogramme of steam raise from 0° to 100°?

This gives us 1÷0·187, or nearly 5·35 kilogrammes; therefore 5·35 kilogrammes of ice-cold water would be raised through 100° degrees, or 535 kilogrammes through 1°. The latent heat of steam according to this experiment is 535 thermal units.

Heat is always absorbed when water evaporates, and it is possible to freeze water by causing it to evaporate rapidly, and at the same time to draw the heat of evaporation from itself. Wollaston's cryophorus[1] is

[1] From *kryos*, icy cold, and *phorein*, a Greek verb derived from *pherein*, to carry, therefore a frost-producer.

a simple instrument which shows this in a very striking manner.



It is a bent tube, having a bulb at each end, and contains water. The air is expelled by boiling the water in the bulb *B* and sealing *A* by means of the blow-pipe. The cryophorus then only contains water and water vapour. The water is transferred to one bulb, and the empty bulb is placed in a freezing mixture. By this means the vapour is condensed, and the vapour to supply the place of that condensed comes from the water in the other bulb. The evaporation goes on so rapidly that the water is soon cooled down to 0° and a solid mass of ice is formed. Carré has invented a machine on this principle for the production of artificial ice. The machine consists of a reservoir, which contains sulphuric acid for the purpose of absorbing the water vapour. A bottle containing water is connected with this reservoir by a tube, and the air is pumped out of the reservoir, the vapour from the water taking its place. This is absorbed by the acid, and owing to the rapid evaporation from the bottle the water is soon cooled to the freezing-point and becomes a mass of ice.

### Tension of Aqueous Vapour.

The outward pressure which a gas exerts against the sides of a vessel containing it is termed its *elastic force*. Water gives off steam or water vapour at all temperatures. If, for example, a glass of water is left in a room for a length of time the whole of the water will disappear as vapour.

In such an inland sea as the Caspian, the evaporation appears to slightly exceed the inflow of such great rivers

as the Volga. The power possessed by water (as well of course as by other liquids) of rising in the form of vapour at all temperatures is named the *elastic force or tension* of aqueous vapour. One way of measuring this elastic force or tension is to place a small quantity of water above the mercury in a barometer. This barometer is of course used for experimental purposes, and it can be easily filled with mercury when it is to be used for showing the tension of aqueous vapour.

The vapour of the water above the mercurial column causes the column in the tube to descend. When the water vapour above the mercury is gently heated, the column gradually sinks, and when the temperature of the vapour has reached 100° C. the mercury in the barometer stands at the same level as that in the trough; in other words, the tension or elastic force of steam at the temperature of 100° C. is equal to the pressure of the air. Now we know that water boils at 100° C. at the normal temperature and pressure, and since from this experiment with the barometer tube we learn that the tension of aqueous vapour at 100° C. is equal to the pressure of the air, it follows that water boils when the tension of its aqueous vapour is equal to the superincumbent pressure of the air.

If the pressure on the surface of water is reduced it boils at a temperature below 100°, and, conversely, if the temperature is increased it boils at a temperature above 100°. At Quito, which is 2914 metres or about $1\frac{4}{5}$ mile above the level of the sea, the mean height of the barometer is about 523 millimetres, and the boiling-point is 90·1°; or at that height the tension of the aqueous vapour is equal to 523 millimetres. For cooking purposes therefore artificial pressure has to be used in order to raise the boiling-point. In certain manufacturing processes the temperature of the water, and therefore the temperature and tension of its vapour, has to be considerably above 100°; and this is particularly the case when the elastic force of the aqueous vapour is employed to perform work as in the steam-

engine. There is a simple experiment, which any one can safely perform, that illustrates the fact that the temperature at which water boils depends on the pressure on its surface, which pressure is transmitted throughout the liquid. A round or globular glass flask with a stop-cock fitted into its neck is about a third or fourth filled with water. After the water has boiled a few minutes, in order to expel the air, the flask is withdrawn from the flame and the stop-cock immediately after closed. The boiling ceases owing to the pressure of the vapour on the water. If the flask is put into cold water the steam inside is condensed, and the pressure consequently diminished, and the water boils again vigorously. If one has not a globular flask with a stop-cock, a common clean olive-oil bottle will suit. After the water has boiled for some time, insert a cork, and remove at the same time the bottle from the flame. The cork must be well-fitting, otherwise the air will get in. If the cork is firmly inserted the boiling ceases. If cold water is poured on the bottle the water again boils. This may be continued for a considerable time. All liquids obey a similar law, but the temperature at which their vapour-tension equals that of the atmosphere varies for each liquid. It is owing to this that liquids can be partially separated by what is termed fractional distillation, the vapour of the liquid present with the highest tension coming off first, and those of the others as the temperature is gradually raised.

When steam is heated apart from water, its elastic force obeys the ordinary law of increase with increase of temperature; but when it is heated in a closed vessel or boiler of a steam-engine, the tension of the steam increases far more rapidly for equal increments of temperature than gases apart from their liquids. The tension of aqueous vapour in contact with its liquid has been experimentally determined for different temperatures. The thermometer used for the determination of the different temperatures is the air thermometer. It has been already

said that a given volume of air at 0° C., when heated to 100° C., receives an increase of 0·3665, or one volume becomes 1·3665. The elastic force of a given mass of gas, whose temperature is 0° C., on being heated to 100° C., receives an increase of elastic force equal to 0·3665 of its original elastic force. It should be here mentioned that though the increase of elastic force is the same numerically as the increase of volume between 0° and 100° of temperature, yet more heat is required to increase the volume from 1 to 1·3665 at constant pressure than is required to increase the elastic force from 1 atmosphere to 1·3665. This is due to the fact that as the gas expands it does work by raising the pressure through a certain distance; it in fact lifts a weight. The amount of heat equivalent to the work done by the air while expanding represents the difference of the heat needed to increase the volume from 1 to 1·3665, and that needed to increase the elastic force at constant volume from 1 atmosphere to 1·3665. If it is known by what amount a given volume of air has increased, it is known at once to what temperature it has been subjected. By means of the air thermometer this can be ascertained, and hence its use in enabling one to arrive at accurate results when owing to the high temperatures the mercurial thermometer would fail.

Owing to the great practical importance of a correct knowledge of the tension of steam in a vessel, when the steam is in contact with the water which gives it off, a table is added, giving the tensions in millimetres from −20° C. to 224·7° C. If one wishes to convert the millimetres to inches, it has only to be remembered that 30 inches are equal to 762 millimetres; 76 centimetres, or 760 millimetres of mercury are taken as the normal pressure of the air. But 760 millimetres are about equal to 29·987 inches. In round numbers 760 millimetres tension may be taken as equal to 15 lbs. to the square inch. Thus from the table we learn that the tension of aqueous vapour at −20° C. is equal to 0·927 millimetres. Now this is equal

to $15 \times \frac{927}{760000}$ or 0·0183 lb. to the square inch. Again, at 224·7° C. the tension of aqueous vapour is equal to 25 atmospheres or $15 \times 25$, that is, 375 lbs. to the square inch. Suppose the pressure of steam is 180 lbs. to the square inch on the piston of a locomotive, it is easy from this table to find its temperature. For 180 lbs. on the square inch are equal to $180 \div 15$, or 12 atmospheres. The temperature of the steam in the boiler is therefore 188·4° C. If the piston has a diameter of 30 inches, the area of the piston is, taken roughly, equal to $\frac{22}{7} \times 15^2$ or 707 square inches. The pressure on the piston is therefore equal to about 1136 cwts or 56·8 tons. The French system of weights, measurement of length, and capacity are invariably used by chemists, and in a less degree by physicists, owing to their great convenience; but the British system is so familiar to English-speaking nations that to many the French system conveys a very indefinite idea either of mass, length, or capacity.

| Temperature, Centigrade. Degrees. | Tension in millimetres of mercury. | Temperature, Centigrade. Degrees. | Tension in atmosphere. |
|---|---|---|---|
| −20 | 0·927 | 100 | 1 |
| −10 | 2·093 | 111·7 | 1·5 |
| 0 | 4·600 | 120·6 | 2 |
| +5 | 6·534 | 127·8 | 2·5 |
| 10 | 9·165 | 133·9 | 3 |
| 15 | 12·699 | 144·0 | 4 |
| 20 | 17·391 | 159·2 | 6 |
| 30 | 31·548 | 170·8 | 8 |
| 40 | 54·906 | 180·3 | 10 |
| 50 | 91·982 | 188·4 | 12 |
| 60 | 148·791 | 195·5 | 14 |
| 70 | 233·093 | 201·9 | 16 |
| 80 | 354·280 | 207·7 | 18 |
| 90 | 525·450 | 213·0 | 20 |
| 100 | 760·000 | 224·7 | 25 |

## Water as a Solvent.

Very little is known about the nature of solution, though it has engaged the attention of chemists for many

years. It is essentially different from chemical combination; for a substance can be dissolved in water in a gradually increasing proportion up to a certain limit termed the *point of saturation*, whereas in chemical combination the substances combine in constant definite proportions and in no others. For example, hydrogen and oxygen combine chemically to form water in the constant proportion of two parts by weight of hydrogen to 15·96 parts of oxygen. There is another compound formed by oxygen and hydrogen, when two parts by weight of hydrogen combine with 31·92 parts by weight of oxygen to form an unstable compound, which may be termed hydrogen dioxide.

In solution, however, the solvent dissolves the solid or liquid in any proportion up to the point of saturation. Although water is the most generally known of all solvents, there are numerous other solvents which dissolve substances on which water has little or no action. Carbon disulphide, for example, easily dissolves ordinary phosphorus, though not what is termed red phosphorus or the non-poisonous variety.

Among the best-known solids easily soluble in water may be mentioned sugar and salt, and among the liquids soluble in water alcohol and acetic acid. Ether only partially mixes with water, and if water is shaken up with oil the oil rises to the surface.

Gases are also soluble in water in very different degrees. Such gases as ammonia and hydrochloric acid are exceedingly soluble in water; for if a bottle having a stop-cock in its neck be filled either with dry ammonia gas or dry hydrochloric, and the neck then be placed under the surface of water, and the stop-cock opened, water will rush up into the bottle owing to the gas being dissolved by contact with the water.

Hydrogen and nitrogen, on the other hand, are very little soluble in water; but such a gas as carbonic acid may be said, as regards solubility, to stand midway between ammonia and hydrogen.

Chlorine is another example of a tolerably soluble gas, forming with water a greenish-coloured solution. The action of solution begins with the smallest conceivable quantity, and goes on continuously like a variable quantity in mathematics, until a maximum is reached which is termed the point of saturation. The degree of solubility of solids depends upon the nature of the solid as well as on that of the solvent, and depends besides on the temperature at which the solution takes place, if we confine ourselves to water as the solvent.

Owing to the fact that so little is known about the nature of a solution, no prediction can safely be made regarding the solubility of any new compound; though such predictions can be made about the chemical properties of elements yet to be discovered.

The quantity of any solid, liquid or gas, that can be dissolved in a given quantity of water must be determined experimentally; and the effect of varying temperature must be determined also in the same manner; though the effect of pressure on the solubility of gas is subject to a known law which will be mentioned later.

## Freezing Mixtures.

In general when a solid is dissolved in a liquid the temperature of the liquid is lowered. This is due to the conversion of sensible heat to the latent heat of liquefaction of the solid substance. If, however, such a salt as carbonate of soda, which has been subjected to a temperature high enough to drive off its water of crystallisation, be dissolved, a rise of temperature occurs, the reason being that water unites chemically with such anhydrous, or waterless salts, to form definite chemical compounds; and, as is well known, chemical combination is attended by a rise in temperature. Many salts when dissolved cause the temperature to sink low enough for the production of ice. The temperature of cold water may be reduced to $-20°$ C. by dissolving sulphocyanide of

potassium in the proportion of 500 grammes of the salt to 400 grammes of the cold water. A well-known freezing mixture is formed by mixing pounded ice or snow with common salt. The mixture of the salt and ice becomes liquid, and the brine or salt liquid thus formed possesses a freezing point as low as —23° C. To obtain this temperature the snow and salt must be mixed in the proportion of 32 parts by weight of salt to as much snow as makes 100 parts by weight of water, that is, if one ounce of salt is taken, a little over three ounces of snow will be needed to secure the most efficient freezing mixture of salt and snow.

Chloride of calcium in crystals, when mixed with an equal weight of snow, gives a freezing mixture that reduces the temperature from 0° to —45° C. In warm countries like India, it is not possible to secure snow except in the region of the mountains; but ice being available it is quite possible to show the effect of a mixture of salt and pounded ice in lowering the temperature.

The solubility of most chemical compounds is increased by an increase of temperature, but this increase does not go on without limit; for in each case when a certain temperature is reached no further increase affects the solubility of the compound. When a saturated solution is allowed to cool (that is, a solution containing as much of the solid as the liquid can dissolve at the highest limit of temperature), the dissolved solid usually crystallises out. It, as a rule, is deposited in the form of crystals, the geometrical form of the crystals depending upon the nature of the dissolved solid. When different chemical substances assume the same geometrical figure they are termed isomorphous, which literally means of the same shape or form.

### Water of Crystallisation.

The crystalline character of many chemical salts, such for example as carbonate of soda, is due to the presence of a definite number of molecules of water in the solid state. This can easily be seen by placing a portion of such a

crystalline salt in a drying oven. The heat applied drives off the water of crystallisation and the salt crumbles to an amorphous powder. The number of molecules of water present depends on the nature of the salt. Alum, for example, contains no fewer than twenty-four molecules of water, and that most useful salt, carbonate of soda, contains ten molecules. In all cases the number of molecules of water is definite for a definite temperature. The temperature at which the deposition of crystals occurs has a decided effect in regard to the quantity of water with which the salt can combine. At the ordinary temperature, that is, the temperature of the surrounding air, a saturated solution of carbonate of soda will, if allowed to stand long enough, deposit crystals of the carbonate containing ten molecules of water. At a higher temperature other crystals containing eight molecules of water are deposited, and at a still higher temperature crystals form containing five molecules.

It is not necessary to heat all salts to drive off their water of crystallisation; for common washing soda and several other salts, when exposed to the air, lose their water of crystallisation, and fall to powder or become coated with a white powder. Crystals which lose their water of crystallisation by mere exposure to the air are said to *effloresce*.[1] Many crystals are not efflorescent, but require heat considerably above the ordinary temperature of the air before giving off their water of crystallisation. Potash alum requires to be heated to the temperature of boiling water before it parts with ten of its twenty-four molecules of water, and in order to reduce the molecules by another ten the temperature must be raised to 120° C.

It should be here mentioned that a molecule of water is represented by the formula $H_2O$, that is, two parts by weight of hydrogen and 15·96 by weight of oxygen. The absolute weight of a molecule is not certainly known; but suppose 105·88 grammes of anhydrous or non-crystalline carbonate

[1] From the Latin inceptive verb *efflorescere*, to begin to blossom forth.

of soda are dissolved in water, and after the crystals formed are dry (of course still retaining the water of crystallisation), let them be again weighed. It will then be found that the original 105·88 grammes weigh 285·48 grammes. The weight is increased by 179·6 grammes. Now, whatever may be the absolute weight of a molecule of water, and whatever may be the absolute weight of a molecule of anhydrous carbonate of soda, the absolute weight of the anhydrous salt would be increased by the same number of the absolute units, namely 179·6. But whatever the absolute weights may be, one molecule of water would weigh 17·96. Now, 179·6 would weigh ten molecules: hence the crystals of carbonate of soda formed at the ordinary temperature contain ten molecules of water. The absolute weight of an atom of hydrogen would be the unit weight just as it is at present; for whatever may be its weight oxygen is 15·96 times as heavy, and so on all through the elements.

To return to alum, it is found that though twenty molecules of water have disappeared at 120° C., the four remaining molecules are not driven off till a temperature of 200° C. has been reached.

Chloride of calcium, acetate of potassium, and certain other salts, unless kept in bottles with ground-glass stoppers, attract water in the form of vapour from the air, and to such an extent that they soon begin to liquefy. They are said to *deliquesce*.[1] Such salts are termed deliquescent.

It was discovered by Dalton in 1841, that when such a salt as carbonate of soda is deprived of all its water of crystallisation and then dissolved in water, the volume of the water is not thereby increased. This is not the case when salts containing their water of crystallisation are dissolved. The volume of the solvent is increased in the latter case by exactly the volume which the water in combination with the salt occupies in the liquid state.

Sir Lyon Playfair, formerly Professor of Chemistry in Edinburgh University, and the late Dr. Joule of Manchester

[1] From the Latin inceptive verb *deliquescere*, to dissolve.

still further investigated the subject of hydrated salts, and found that carbonate of soda crystallising with ten molecules of water, as well as the phosphates and arsenates which crystallise with twelve molecules of water, possesses the remarkable property that the volume of the whole molecule of the hydrated salt is exactly the volume which its water of crystallisation would occupy if frozen to ice. To make this more intelligible, it may be explained that the molecule of hydrated carbonate of soda is expressed in symbols as $Na_2CO_3+10\ H_2O$. It will be seen from the table of atomic weights that $Na_2CO_3=105{\cdot}88$ and $10\ H_2O=179{\cdot}60$. The weight of the whole is therefore $105{\cdot}88+179{\cdot}60$ or $285{\cdot}48$. If, therefore, 285·48 grammes of the hydrated salt are dissolved in water, the increase of the solvent will be that due to 179·60 grammes of water; but one gramme of water at 4° is equal to one cubic centimetre, the increase in volume will therefore be equal to 179·60 cubic centimetres. Now, according to the researches of Joule and Playfair, if the molecule of the hydrated salt, or if 285·48 grammes be taken, the volume occupied by this amount, is equal to that occupied by 179·60 grammes of ice. To find this volume it is only necessary to know the specific gravity of ice, and that is 0·918: $179{\cdot}60\times1=0{\cdot}918\times v$, hence $v=179{\cdot}60\div0{\cdot}918$, or $195{\cdot}642$. Thus 179.60 cubic centimetres of water at 4° occupy 195·642 cubic centimetres as ice at 0°.

But as the increase of volume of the solvent is exactly due to the water in combination with the salt, it would appear that the anhydrous salt occupies the intervening spaces of the water without thereby increasing its volume.

When treating the subject of the freezing of water, it was stated that when salt water freezes the salt is not all expelled as is sometimes stated; but a certain portion of it is also frozen. The late Professor Guthrie of London investigated this subject, and termed the solids thus formed cryohydrates.[1] Guthrie found that a dilute solution of

[1] From Greek *kryos*, icy cold, and *hydor*, water.

common salt when cooled down to —1·5° C. begins to form crystals, and the formation of these crystals continues until the temperature sinks to —22° C.

A saturated solution begins to crystallise at —7° C., having the composition of one molecule of salt and two molecules of water. These crystals continue to be deposited until the temperature has sunk to —22° C., and at —23° C. another definite cryohydrate separates out.

It is easy to see that these compounds explain the lowering of temperature which takes place when certain compounds are mixed together; and in order to secure the most efficient freezing mixture the compound should be mixed in the proportion in which they occur in a cryohydrate.

### Absorption of Gases by Water.

As has been asserted, all gases are more or less soluble in water, some, such as ammonia, being extremely soluble, others, such as chlorine and carbonic acid gas, being moderately soluble, or capable of being collected over water, and others again, such as hydrogen and nitrogen, being slightly soluble. The solubility therfore depends (1) on the nature of the gas; (2) on the temperature; (3) on the pressure to which the gas in contact with water is subjected. The solubility of most solids increases with the temperature, but in the case of gases the reverse holds good; for generally the solubility of the gas diminishes as the temperature increases, the rate of diminution of course varying with each gas. As far back as the year 1803, William Henry discovered that the quantity of a gas absorbed by water varies directly as the pressure. This means, that the temperature remaining the same, water dissolves the same volume of a gas under whatever pressure. For example, a cubic centimetre of oxygen under a pressure of ten atmospheres has the same fraction of the volume dissolved as a cubic centimetre would have if the pressure was only one atmosphere or half an atmo-

sphere; from this it is clear that when a volume is under a pressure of ten atmospheres ten times the mass of oxygen is dissolved as when an equal volume is under a pressure of one atmosphere. When the pressure is diminished the equilibrium no longer exists, and a portion of the gas escapes from the liquid. This is well seen on opening a bottle of soda water, where a much greater mass of carbonic acid gas has been absorbed than can be retained under the ordinary atmospheric pressure. Two years after Henry had discovered this law he and Dalton extended it to mixed gases and proved that when a mixture consisting of two or more gases is shaken up with water what is termed the absorptiometric equilibrium is reached, when the pressure of each gas dissolved in the liquid is equal to that of the remaining undissolved portion of the gases. Here it is necessary to say that there must be a finite relation between the volume of the liquid and that of the gas. If a very large volume of water is shaken up with a small volume of a gas, as a matter of course, more of the gas will be dissolved than would be the case if a small volume of water were taken. The amount of each gas absorbed in such a mixture depends upon the pressure exerted by that gas, and upon what is termed the *absorption coefficient* of the gas. By absorption coefficient is meant the fraction of the volume of the gas absorbed by an equal volume of water.

For example, a vacuous vessel of a certain capacity has a certain mass of oxygen introduced. However small the mass may be, it will fill the vessel. If this oxygen be then shaken up with water, a certain fraction of its volume, depending on the absorption coefficient, will be dissolved.

If into the same vessel a certain mass of nitrogen is next introduced, a certain fraction of its volume will also be dissolved, depending on its absorption coefficient: the same would be the case with hydrogen. The introduction of the other gases would increase the pressure, yet the fraction of the volume of each gas dissolved would be

exactly the same as if none of the other gases had been present; and the mass of each gas dissolved depends entirely on the pressure it would exert if it had occupied the whole space which is occupied by the mixed gases. The fact that a definite volume of water has dissolved as much of a particular gas as it is capable of dissolving at the given temperature does not in the least interfere with its power of dissolving another gas precisely the same in amount as if it contained no gas in solution previously.

The fact that a mixture of gases, occupying a certain volume, exerts a pressure equal to the sum of the pressures of each gas which forms the mixture, shows that the pressure of each constituent gas is equal to the pressure it would exert on the water if none of the other gases were present; and hence the amount of each gas absorbed by the water is exactly the same as if it had been present by itself. This has been termed *Dalton's law* of partial pressures. The mixed gases must be such as do not act chemically on each other. The fraction of the volume of a gas at 0° C. and one atmosphere of pressure, absorbed by an equal volume of water at the same temperature, as we have seen, is termed the *Absorption Coefficient.* For oxygen, this at the normal temperature and pressure is 0·04114; for nitrogen 0·02035; for carbonic acid gas 1·80; hydrogen 0·019; nitrogen monoxide 1·13. At 10° C. the volume of oxygen absorbed is 0·033; nitrogen 0·016; hydrogen 0·019; carbonic acid 1·18; nitrogen monoxide 0·92. At 20° C., oxygen 0·028; nitrogen 0·014; hydrogen 0·019; nitrogen monoxide 0·67; carbonic acid 0·90.

It will be seen from this that the solubility decreases with a rise of temperature. This law may be illustrated by taking the atmosphere. One hundred volumes of air contain 20·96 volumes of oxygen, and 79·04 volumes of nitrogen. Since the 100 volumes are under the pressure of one atmosphere, according to the law of partial pressures the oxygen present would, if occupying the same volume, by itself exert a pressure of 20·96÷100, or 0·2096 of an

atmosphere. For the same reason the partial pressure exerted by the nitrogen is 0·7904 of an atmosphere. The absorption co-efficient of oxygen at 0° C. and under one atmosphere of pressure is 0·04114; and that of nitrogen 0·02035. The solubility of each gas is proportional to its partial pressure; this may be expressed in symbols: let $p$ be the pressure in atmospheres; $m$ the amount of the gas dissolved, then $\frac{m}{p}$ = a constant quantity. For oxygen at the normal temperature and pressure this constant quantity is 0·04114, therefore $m = p \times 0{\cdot}04114$. In the case of the atmosphere the amount of one volume of oxygen dissolved is $0{\cdot}2096 \times 0{\cdot}04114$ or $m = 0{\cdot}008629$. For nitrogen the amount is $0{\cdot}7904 \times 0{\cdot}02035$, or $m = 0{\cdot}016084$. From these results it is easy to calculate the percentage composition of the air dissolved.

The whole amount of air dissolved when one volume is taken is $0{\cdot}008629 + 0{\cdot}016084$ or 0·024713. Then if 0·024713 of dissolved air contains 0·008629 of dissolved oxygen, how much oxygen, or how many volumes of oxygen would 100 volumes of dissolved air contain? This is expressed as follows: 0·024713 of air contains 0·008629 of oxygen, therefore 1 volume of dissolved air contains $\frac{0{\cdot}008629}{0{\cdot}024713}$ and 100 contains $\frac{0{\cdot}008629}{0{\cdot}024713} \times 100$, or 34·91 volumes of oxygen. For nitrogen $\frac{0{\cdot}016084}{0{\cdot}024713} \times 100$ or 65·09.

This is in perfect agreement with the relation between the dissolved gases found by experiment.

One of the most interesting results of the law of partial pressures is the possibility of separating the oxygen of the atmosphere from the nitrogen by repeated absorption. Mallet, who first proposed the method, boiled water containing the dissolved gases, collected the mixture, and again dissolved, and so on. He found that after the eighth absorption, the gas contained 97·3 per cent. of oxygen. This depends upon the law of partial pressures; for 100 volumes of air contain 79·04 volumes of nitrogen and 20·96 volumes of oxygen. But 100 volumes of dissolved

air after the first absorption contain 65·09 volumes of nitrogen and 34·91 of oxygen; the percentage of oxygen being considerably higher, and that of nitrogen considerably lower. This increase in the percentage of oxygen and diminution in that of nitrogen continues until after the eighth absorption. The gas then obtained consists of 97·3 per cent. of oxygen.

## Natural Waters.

None of the different forms of water met with in nature are free from impurities of one kind or other. This is a natural consequence of the solvent properties of water as well as of the mechanical action of water on substances which are not dissolved by it. The mechanically suspended impurities can be separated by subsidence or by filtration. Substances dissolved in water cannot be separated either by filtration or subsidence, but must be separated either by distillation or by some chemical process. The purest of natural waters is rain-water, but even this contains impurities derived from the atmosphere besides dissolved gases, and as soon as it comes in contact with the earth it takes up into solution certain soluble constituents of the earth's crust through which it percolates. The rivers and springs become more and more impure, owing to the solvent action of water as they flow towards the sea from which they originated.

By filtering drinking water through a layer of charcoal, many impurities are got rid of, and the water is improved in other respects. The soluble constituents of water are either fixed or volatile. Distillation frees water from all non-volatile snbstances, but ordinary distilled water always contains ammonia. Volatile substances, into whose composition nitrogen enters, can be got rid of, provided the water is placed in contact with permanganate of potassium and caustic potash, and afterwards distilled. It is easy to detect the presence of ammonia in ordinary distilled water by means of Nessler's reagent. This consists of an alkaline

solution of iodide of mercury in iodide of potassium. If some of this reagent be added to about a hundred cubic centimetres of distilled water, which is poured into a cylindrical glass with a foot, placed on white paper, a yellowish tint will be seen to be acquired by the water if small amounts of ammonia or salts containing ammonia are present; while if ammonia, whether free or combined, be present in considerable quantity a brown precipitate will be formed.

In order to completely free water from nitrogenous substances it is necessary to re-distil it, after it has been placed in contact with permanganate of potash and caustic potash. By means of these compounds, the organic substances are oxidised, and after about one-twentieth of the water has come over, the distillate is generally found quite free from ammonia, and leaves no residue when evaporated. If ammonia be still detected in the distillate, the addition of a small quantity of acid sulphate of potash fixes the ammonia by combining with it, and the distillate is then completely free from nitrogenous matter.

The gases dissolved in water can only be expelled by prolonged boiling. Rivers contaminated by sewage possess the power of becoming purified. This results from the action of the oxygen contained in the air. A series of elaborate analyses made by the late Professor Miller of King's College, London, conclusively proved this in regard to the Thames water.

The beneficial effects derived from certain natural mineral waters depend entirely on the substances which are held in solution. Water is also characterised by the terms hard and soft, according as it holds in solution larger or smaller quantities of lime or magnesia. These exist either in the form of carbonates or sulphates. One can easily ascertain whether water is hard or soft from the more or less quantity of soap needed to form a lather or froth. This arises from the fact that the lime and magnesia contained in hard waters combine with the fatty

acid which forms an essential ingredient of the soap. By this combination insoluble compounds are formed, and until the lime or magnesia is by this means abstracted from the water no lather can be obtained. When the hardness of water is due to the presence of lime in solution, it is said to be temporary, and for this reason that it can be rendered soft, either by boiling or by the cautious addition of milk of lime, which combines with the carbonic acid dissolved in the water.

It is owing to the presence of carbonic acid that the water is capable of holding the lime in solution; and when just enough milk of lime is added to the water to form carbonate of calcium or lime with the carbonic acid gas in solution, the water is no longer capable of holding the lime in solution, and it, after a time, subsides along with the carbonate formed by the addition of the milk of lime. By milk of lime is meant a solution of lime in cold water. Boiling also expels the carbonic acid gas, and by this means the water becomes soft. This is the cause of boiler crust. When water containing magnesia is boiled no effect is produced as far as regards the rendering of the water soft. Water, therefore, containing magnesia is called permanently hard.

The late Dr. Clark, of Aberdeen, proposed a simple method of ascertaining the amount of hardness of water.

The principle of this method consists in ascertaining how many measures of a solution of soap are required to form a lather with a definite volume of water whose degree of hardness is known. The soap solution is prepared as follows: 10 grammes of good Castile soap are dissolved in 1 litre of alcohol, which is diluted with water to the extent of 65 per cent., and the strength of the solution is made such that 1 cubic centimetre will exactly precipitate 1 milligramme of carbonate of calcium when contained in a certain volume of water. For the purpose of making what is termed a standard solution of the soap, 1 gramme of calc spar is dissolved in hydrochloric

acid; the solution containing the calcium chloride thus formed is then evaporated till it is dry, and the excess of the hydrochloric acid by this means is driven off. The dry residue left after evaporation consists of chloride of calcium. This is then dissolved in a litre of distilled water. A litre contains 1000 cubic centimetres; each cubic centimetre would thus contain a thousandth part of a gramme, or 1 milligramme. If the degree of hardness is to be estimated in grains per gallon, the standard soap solution is diluted so that 1 cubic centimetre precipitates one thousandth part of a grain; and the soap solution is made of such strength as to correspond to 1 grain per gallon.[1] The soap solution is gradually added from a burette, or graduated glass tube with a glass stopcock. The water is shaken vigorously until a permanent lather is formed. The number of cubic centimetres needed for this purpose is at once ascertained by reading the scale on the burette. Each division corresponds to a certain quantity, and from the number of the divisions required the hardness of the water is estimated. The hardness is generally calculated into parts per 100,000, instead of per cent.

Water is said to be hard by so many degrees, or the hardness is expressed in degrees. By this must be understood the number of parts by weight of calcium carbonate, or magnesium carbonate, or other calcium salts which are contained in a gallon or in 100,000 parts of the water. River water may be either hard or soft, depending on the character of the strata of the countries through which it flows. If the river bed be granite, the water will not be able to dissolve it, and will consequently remain soft. The mechanical action of water must not be confounded with its solvent action. Even

[1] A gallon is equal to 70,000 cubic centimetres, and if 1 cubic centimetre of the soap solution be needed to form a permanent lather with 70 cubic centimetres of water, this corresponds to a grain of calcium chloride per gallon.

river beds composed of granite are gradually deepened, and the mechanical action of large volumes of water in motion is well known.

Much could be written on the various forms assumed by water; but these details can easily be found by those interested in making a special study of water in all its forms and modes of action. These latter will be found in works treating of hydro-mechanics, where the employment of high mathematical analyses is of frequent occurrence. It is of the chemical and physical properties of water that we have been writing; and these are of such interest and importance to mankind that a knowledge of them ought to form part of the mental acquisitions of every child: at least in their more elementary form. Here somewhat full details have been given regarding the methods of ascertaining the composition of water. This has been thought necessary, as these details can only be found in large treatises often inaccessible to the ordinary student.

# MOLECULES AND MOLECULAR FORCES

# MOLECULES AND MOLECULAR FORCES

THE following account of the modern views regarding molecules is taken from a lecture delivered by Professor Clerk Maxwell, at Bradford, in 1873.

If we take a drop of water and divide it into two, each part seems to retain all the properties of the original drop, except in regard to size. Each of the parts can be again divided into two, and every resulting part subdivided until a limit is reached, when the divided portions would become too minute to be either seen or handled. Yet there is no doubt that if our senses and our instruments were more delicate, the process of division might be carried still further. The question now arises whether these particles of water, which are continually becoming smaller, are capable of infinite subdivision. It is believed that they are not, and that after a certain number of operations, we should come to an ultimate molecule of water or the smallest entity retaining all the properties of water, and that if it were possible to divide the molecule further, the only result would be to separate it into its two chemical constituents of oxygen and hydrogen. By this process of subdivision we should arrive in imagination at the atom, which, as the word implies, is something which cannot be cut (*a*, not, and *temno*, I cut). Every substance whether simple or compound consists of molecules. If the molecule be divided, its parts are molecules of a substance or substances different from that of which the whole is a molecule. Sir William Thomson has arrived at the following result in regard to the size of the molecules of water. He imagines a drop of water to be magnified until it becomes as large as the earth, the diameter of which is 8000 miles. If all the molecules of which the drop is made up were magnified

in the same proportion, he concludes that a single molecule would then appear somewhat larger than a shot, and somewhat smaller than a cricket ball. This conclusion enables us to realise the exceedingly small size of the molecules of matter, and renders it certain that the most powerful microscope will never bring them within the range of vision.

The molecules of all bodies are in motion even when the bodies themselves appear to be at rest. In the case of a solid body these motions are confined within a very narrow range, and are consequently imperceptible. Each molecule vibrates about a certain mean position from which it does not depart to any appreciable extent, being kept in this position by the neighbouring molecules. The molecules of liquids and gases are not confined within definite limits, but diffuse themselves throughout the whole mass. When a gas is confined in a vessel, it exerts pressure against the sides. This pressure is due to the impact of the molecules on the sides of the vessel. The succession of blows is so rapid that the effect produced does not differ from a continuous pressure. Suppose the molecules to have a given velocity, but that the number of them can be increased or diminished. Then since their velocity is constant, each molecule will strike the sides of the vessel the same number of times; and with the same impulse each will contribute an equal share to the whole effect. From this it follows that the pressure on the sides of a vessel of given size is proportional to the number of molecules it contains, or to the quantity of gas contained in the vessel. An increase or decrease in the number of molecules in a vessel of given size is the same as an increase or decrease in the density of the gas; so that the statement just given is in agreement with Boyle's law, that the pressure of a gas varies as its density. If the velocity of the molecules be increased, each molecule will strike the sides of the vessel a greater number of times in a second, and the strength of each blow will be increased in the same proportion, so that the pressure will increase as

the square of the velocity. This increase of velocity corresponds to a rise of temperature in the gas. This also explains the fact that if the pressure remain constant all gases expand by the same amount for a given rise of temperature. When molecules of different masses are mixed together, the greater masses move more slowly than the smaller, but all the molecules have on the average the same momentum. It follows from this that in a cubic inch of any gas at a fixed temperature and pressure, there is the same number of molecules. This is the law of Avogadro. At the temperature of the freezing-point, the average velocity of the molecules of hydrogen is calculated to be about 2033 yards per second; the velocity of the molecule of oxygen is one-fourth of this. This explains the diffusive power of gases. The velocity of the molecules of air in a room may be reckoned at about seventeen miles per second. Since molecules are moving in all directions, they are continually coming into collision with each other, and after colliding the path of each is changed, so that they move off in new directions. Since a molecule is thus having its course continually changed, it may, notwithstanding its great velocity, require a long time to move far from its starting-point. Ammonia is easily recognised by its smell, and the velocity of its molecules is 656 yards per second. This velocity is so great that if there were no obstacles to the motion of the molecules its smell ought to pervade a large room as soon as a bottle of it is opened; but owing to collisions with molecules of air, it takes a considerable time to reach the more distant parts of a room. Calculations have also been made in regard to the average distance which a molecule travels between two successive collisions, and from this and the known average velocity, the number of collisions in a second can be inferred. The results for hydrogen are as follows. The average distance travelled between two collisions is about four millionths of an inch, and the number of collisions per second eighteen thousand millions.

The difference between a gas and a liquid lies in the fact that for the greater part of its time, a gas is describing its free path, that is, moving without coming into contact with other molecules; whereas in a liquid the molecules have hardly any free path, and are constantly encountering other molecules. As the result of this, the propagation of motion from one molecule to another takes place much more rapidly in a liquid than the transference of the molecules themselves.

The conclusion at which Sir W. Thomson arrived as to the size of a molecule of water has already been stated. Professor Clerk Maxwell gives the following results as to the size of the molecules of hydrogen. Fifty millions of them in a row would occupy one inch, and $10^{24}$ of them would weigh about seventy grains. In a cubic yard of any gas at the standard temperature and pressure, there are about $25 \times 10^{18}$ molecules.

A molecule appears to be always the same, incapable of growth or decay, of generation or destruction. The sun and stars appear to be built up of molecules of the same kind as those which are found on the earth. With regard to molecules, Professor Clerk Maxwell writes: None of the processes of nature, since the time when nature began, have produced the slighest difference in the properties of any molecule. We are therefore unable to ascribe either the existence of the molecules, or the identity of their properties to the operation of any of the causes which we call natural. On the other hand, the exact equality of each molecule to all others of the same kind gives it, as Sir John Herschel has well said, the essential character of a manufactured article, and precludes the idea of its being eternal and self-existent.[1]

[1] The meaning of this passage is that molecules are to be regarded as the manufactured articles or bricks of which the universe has been built up; that they were created and have always remained such as they now are—not subject to change or any process of development through the operation of natural causes.

*Molecular Forces.*—Between the molecules of which bodies are composed, there exist powerful forces of attraction and repulsion. As an example of the former we have the *attraction of cohesion.* This force acts powerfully when the distance between the molecules is small, but ceases when that distance is sensibly increased. At the same time the molecules are not in actual contact, even in the densest bodies. This is shown by an experiment which the Florentine Academicians made in 1661, for the purpose of ascertaining whether water is compressible or not. A thin globe of gold was filled with water, and after the opening had been hermetically sealed, pressure was applied. If water were incompressible, the pressure would either burst the globe or force the water through it. The result showed that water was forced through the pores of the gold. This, together with the fact that bodies can be compressed, proves what is called the *porosity* of bodies. When bodies are compressed so that the molecules are forced nearer to each other, strong forces of repulsion are developed by the pressure, which tend to restore the molecules to their former position. If when the external pressure has been withdrawn, the molecular forces can bring back the body to its original configuration, the body is said to be *perfectly elastic* under compression. All liquid and gaseous bodies possess this property, since they regain their original volume when any pressure to which they have been subjected is withdrawn. A solid is said to be *perfectly* elastic which returns exactly to its original shape when, after being subjected to constraint, the force of constraint is removed. If it only partially recovers its original form, it is said to be *imperfectly* elastic, and the body is then permanently deformed. No solid bodies are *perfectly* elastic, although ivory, glass, and india-rubber possess the property in a high degree. Other solid bodies, such as lead and clay, have very little elasticity. If a ball of ivory be allowed to fall from a given height on a smooth slab of marble, it is found to rebound to nearly its original

height. It is believed that during the short time the contact with the marble lasts, the ball has undergone a slight deformation, and that the action exerted by the molecular forces in restoring the ball to its original shape causes the rebound. For practical purposes nearly all solid bodies may be considered *perfectly* elastic up to a certain limit. For example, the main-spring of a watch may continue to act for years without undergoing any appreciable change, provided the constraint to which it is subjected does not exceed a certain limit. For degrees of constraint beyond the limit peculiar to itself every body will be imperfectly elastic. It evidently becomes a matter of great practical importance in ensuring the safety of structures to attend carefully to the limits of elasticity of the materials employed. Imperfectly elastic bodies when subjected to constraint undergo deformation, and this deformation gives rise to the properties of *ductility* and *malleability* possessed by certain metals. Ductility means that the metal can be drawn out into fine wire. Platinum, gold, and silver possess this property in a very high degree. Dr. Wollaston succeeded in drawing out a platinum wire to such a degree of fineness that 3000 feet of the thread weighed only one grain, and 140 of the threads were required to make the thickness of a single silkworm's thread. Gold is nearly as ductile and malleable as platinum. Goldbeaters can, by hammering, reduce gold to such thin leaves that 360,000 must be laid on the top of each other to make up the thickness of one inch. Eighteen hundred of them are equal in thickness to a single sheet of common paper. When, in the case of imperfectly elastic bodies, the molecular forces do not succeed in restoring the body to its original form, and the body undergoes deformation, there is a certain loss of molecular energy, The energy which has disappeared takes the form of heat, as is shown by the rise in temperature of the deformed body.

The *elasticity of extension* is a property which belongs to solid bodies. When weights are applied to the ends of

rods or wires, and the molecules forcibly separated, the effort which they make to recover their original position gives rise to this kind of elasticity. It does not belong to liquids or gases; for in the case of liquids the molecules may be separated without the development of any recovering force, and in the case of gases the molecules tend to separate from each other. Experiments are made by fastening the end of a wire of known sectional area to a fixed beam. The wire is first gently weighted in order to remove from it all twists. Two points or lines are marked on the wire, the marks being an inch or two from the ends. The distance between the marks is measured by a cathetometer. This consists of a vertical bar, which is divided into inches and decimals of an inch. A telescope slides along the bar with its axis horizontal. The telescope is moved until the observer has one of the marks in the field of view. It is then made to slide along the bar until the other mark becomes visible. The distance between them can thus be ascertained from the graduations on the bar. Different weights are successively attached to the wire, and the new distances between the marks measured. The differences of their lengths will give the elongations produced by the different weights. By experiments conducted as above described the following facts have been ascertained:

(1) Up to a certain extension, rods and wires possess perfect elasticity, that is, they resume their original length when the stretching force has been removed. The time required to return to their original length varies with different bodies from one second to several days.

(2) After passing this limit of extension, rods and wires recover their original length less and less perfectly, and exhibit *ductility*.

(3) When the extension of a rod or wire reaches a second limit rupture takes place.

Within the limits of *perfect* elasticity the laws proved are as follows:—

(1) For the same solid and the same cross section the elongation is proportional to the stretching force and to the length of the wire.

(2) For the same solid and the same length the elongation is proportional to the cross section. These two laws may be both expressed by the relation $e=k\frac{wl}{s}$, where $e$ is the elongation, $l$ the original length of the wire, $s$ the cross section, and $w$ the stretching weight, and $k$ a constant quantity peculiar to each body, and determined by experiment. If one foot be the unit of length, and one square inch the unit of area $e=k\,w$, or $\frac{1}{k}=\frac{w}{e}$, where $w$ is the weight which produces the elongation $e$ in a rod one foot in length and one square inch in section. If we assume that the law of perfect elasticity holds good for any amount of lengthening, it follows that by applying a proper force, the rod or wire could be doubled in length. In the case above supposed the rod one foot long and one square inch in section will be stretched until its length is 2 ft., $e$ is then equal to unity and $\frac{1}{k}=w=E$. The quantity $E$ is called the modulus of elasticity. It is the weight which would elongate a bar one foot long and one square inch in section to two feet.

*Elasticity of Torsion.*—Experiments on the elasticity called into action when wires are twisted are made by an instrument called the Torsion Balance. A wire is fixed at its upper extremity, and to the lower end a needle is attached at right angles to the wire. A graduated horizontal circle is fixed immediately below the needle, having its centre in the same vertical line as the wire. The wire is twisted by turning the needle round in the horizontal plane. The angle through which it has been turned is measured by reading the graduation on the horizontal circle. This angle is called the *angle of torsion.* The force which is required to retain the needle in the position

into which it has been turned is called the *force of torsion.* When the needle has been turned through a certain angle, and then left to itself, it gradually regains its original position of equilibrium by a series of oscillations performed on either side of this position. From the observation of these oscillations, the molecular forces to which the wire has been subjected when distorted are calculated. Experiments on the elasticity of torsion were carried out by Coulomb and Wertheim, both of whom arrived at the same laws of torsion, the former by experimenting with wires, and the latter with rods. The laws of torsion are:

(1) The angle of torsion for wires of the same material and cross section is proportional to the moment [1] of the force applied, and to the length of the wire.

(2) The angle of torsion for the same wire and the same length and the same force is inversely proportional to the square of the cross section of the wire.

[1] By 'moment of the force applied' is meant the product of the force into the perpendicular distance of its point of application from the axis about which the needle turns.

# BACTERIA

# BACTERIA

THE importance of knowing something about the organisms which are named Bacteria is becoming more generally recognised; and especially since the recent researches of the eminent German specialist Dr. Koch. Bacteria[1] play such an important part in connection with fermentation, putrefaction, and the Germ Theory of disease, that some knowledge of these insidious and deadly enemies of both man and the lower animals ought to be possessed by every one who believes in the future probability of some of the most dreaded and deadly diseases being successfully treated.

It has long been known that water which is or has been in contact with organic matter, that is, flesh, vegetable matter, or some of their constituents, soon assumes a turbid or cloudy appearance, and becomes covered with a film. If the scum which covers the surface of the water be examined with a microscope of high magnifying power, say a one-eighth inch objective, a truly wonderful exhibition of the lowest forms of life will be observed. Many of the organisms representative of the lowest forms of animal life, which are quite invisible to the naked eye, such as the Infusoria, now make themselves manifest, but these seem very large in comparison with a multitude of diminutive individuals, which are all classed as Bacteria. These have usually the appearance of small spheres, rods, or threads, capable of movement by means of lashes, or appear quivering together, as is usually the case with small floating

[1] The plural of a post-classical Latin word *bacterium*, from the Greek *bakterion*, diminutive of *baktron* a stick or rod, and therefore *little stick* or *staff*.

particles, or are found imbedded in a jelly-like flake in an almost passive condition.

If these bacteria continue to be observed it will soon be seen that they multiply with most extraordinary rapidity by cross division, one soon becomes a thousand and the small specks first appearing will, if the liquid contain sufficient food, shortly form a mass completely filling the vessel. Wherever matter is found, the constituents of which form the essential parts of animal or vegetable tissue (organic matter), and when this organic matter is undergoing the process of decomposition these bacteria abound. They are the never-failing concomitants of disease, decay, and death, and exist in sores, and in diseased organs within the living body. These lowly organisms are so numerous, and so common in all media, that they formed a fascinating subject of eager investigation to the early workers with the microscope.

As early as the seventeenth century, when microscopes were, compared to those of the present day, exceedingly imperfect, some of these lowly organisms were described by Leeuwenhoek. Two genera, Monas and Vibrio, were established by O. F. Müller, in 1773. From this period, further progress was almost at a stand-still for more than sixty years, until Ehrenberg in 1838, as well as Dujardin, took up the subject. They considered that the forms of bacteria which they described belonged to the series of lowly organised animals among the Infusorians, and classed a large number under the term *Vibrionia*.

Naturalists, at the time when these researches were being pursued, supposed that the power of locomotion was one of the essential characteristics of animals; but it is now a matter of certainty and of general knowledge that the simplest forms of vegetable organisms possess a power of locomotion; though this power is exceedingly limited in the higher forms.

[1] Hence the division to which *bacteria* belong is termed Schizomycetes, from the Greek *schizein* to split, and *mykēs* a fungus.

No argument can now be adduced in support of the animal nature of organisms founded on the power of locomotion which they possess. In addition to the fact that bacteria, on account of their power of locomotion, were referred to the animal series by early observers, another reason for this reference was based on the then supposed distinctive difference between plants and animals as regards their manner of feeding. It is generally admitted that plants containing a green colouring matter termed chlorophyll[1] derive all their carbon from the carbonic acid gas, or more correctly expressed, the carbon dioxide existing in relatively small quantities in the air. This gas is made up of carbon and oxygen, and is given off whenever coals, wood, or other combustible substances containing carbon are burned. Both animals and plants exhale this gas (carbonic acid) during the process of respiration.

Chlorophyll-bearing plants alone possess the power of decomposing carbon dioxide mixed with water; and this can only be effected under the influence of light. So far as has been ascertained, the chlorophyll corpuscles, under the influence of light, undoubtedly partially decompose the carbon dioxide; and by means of the residue organic compounds are formed. Oxygen is given out during this process, and the first compound which can be detected in plants as a result of this is starch. Many other processes occur during the growth of the plant, and many other remarkable compounds are formed in the course of the building up of the vegetable tissues. It is known that the chlorophyll-bearing plants derive all their food from inorganic substances.

The matter necessary for the nutrition of plants is thus of a much simpler character than that needed for the nutrition of animals. The food of animals must consist of compounds formed by plants or of other animals that have obtained their food from plants. Animals cannot directly feed on inorganic substances dissolved in water, as is the

[1] From the Greek *chloros* greenish, and *phyllon* a leaf.

case with plants. It was owing to the recognition of this difference between plants and animals that considerable difficulty arose in regard to the place of bacteria; *i.e.* whether they belonged to the vegetable or animal kingdom. The bacteria are devoid of chlorophyll, by means of which the carbon dioxide is utilised. Again, the conditions under which they occur clearly show that they derive their nutriment from the products of decomposition of plants or animals; and this, from a physiological point of view, very much in the same way as animals derive their food. In the course of further researches, most elaborately conducted, the conclusion forced itself upon those most capable of judging, that the distinction between plants and animals, so evident in the higher forms, viz., the power of the former of living on inorganic substances and the want of this power in the latter, could not be received as a basis of classification or as a hard-and-fast line of demarcation between plants and animals.

Observers were not long in seeing that, though bacteria and other kindred organisms did not derive their food from inorganic substances, like the majority of plants, and that though these lowly organisms feed much in the same way as animals, yet, from a study of their structure and development, there could be no doubt that they ought to be referred to the Vegetable Kingdom.

The life-history of these minute organisms bears such a striking resemblance to that of certain unmistakable vegetables, such, for instance, as the simple Algæ, that it was found impossible to separate them from the latter. There is now not the very remotest doubt but that the bacteria are real fungi. Cohn in 1853 clearly proved, from careful and skilful investigations regarding the structure and life-history, morphology, and development of bacteria, that they are real plants; and the researches of other investigators have without exception confirmed Cohn's conclusions.

Nägeli, another German investigator, in 1857 continued Cohn's investigation, but separated the bacteria from algæ, and referred them to the Schizomycetes or fungi propagated by division, as the term implies. The bacteria, or Schizomycetes, have been defined as 'extremely small, single-celled, fungoid plants without chlorophyll, remaining single, or united in loose colonies, reproducing rapidly by cross division or by the formation of spores, often occurring in great crowds enveloped in a jelly-like secretion, or separately, with the power of energetic movement, and almost always associated with the decomposition of albuminoid matter or substances.'

It may be here stated that albumen is only found in animals or vegetables, in other words, in organic bodies.

*Terminology.* A generally accepted method of terminology is of the greatest importance, otherwise endless confusion would result from the fact that investigators used different terms to connote the same characteristics.

It has been proposed to use the term Micro-organism as a general word when the position of the form under investigation is not yet determined.

Littré has accepted the French word Microbe,[1] first used by Sédillot in 1878, and it is very widely used. It simply means a small living organism, and was employed simply to avoid discussion as to whether low organisms, like bacteria, should be classed as plants or animals. Microbe is now virtually equivalent to these lowly fungi.

Bacterium, as well as bacillus,[2] is, properly speaking, the name of a distinct genus of Schizomycetes, but these generic names have been too indiscriminately used, and are confined to popular designation.

Thus, in connection with tuberculosis[3] the fungoid

[1] From the Greek *mikros* small, and *bios* life.

[2] From the Latin *bacillus* or *bacillum*, dim. of *baculus*, a stick or staff, hence a small staff.

[3] From the Latin diminutive *tuberculum*, a small swelling, and the termination *osus*, full of.

growth which causes this disease is popularly designated Bacillus tuberculosis. It is best to use the term Bacteria as equivalent to the technical term Schizomycetes.

Some account will now be given of (1) the distribution, (2) form and structure, (3) life-history, (4) general classification, (5) more important forms, and (6) methods of research.

*Distribution.*—Bacteria may be said to be found everywhere; they occur in earth, air, and water; they are found in men's mouths, on the hair of the head, on the toes, on the walls of houses, in chalk and coal, in food and drink, and are in great numbers associated with disease, death, and decay.

It is said that it is scarcely an exaggeration to speak of the 'omnipresent bacillus.' The important relation of these organisms to health has recently stimulated many investigators to devise means for ascertaining, with an approach to numerical accuracy, the number of the organisms existing in a certain quantity of air or water.

It is an undoubted fact that when air is laden with these organisms, this is owing to conditions inimical to health, and in general the same, under certain conditions, may be said of water. It is for this reason that a special laboratory, presided over by M. Miquel, for investigating the time and seasons of atmospheric germs, has been established in the observatory of Montsouris in Paris.

Researches have been recently made also in Britain for the purpose of ascertaining the conditions most favourable to the presence of micro-organisms in the air. With this purpose in view the air in lodging-houses, school-rooms, factories, etc., has been carefully examined, and the late Professor Carnelly devoted much time and attention to these investigations in Dundee.

M. Miquel found that in a cubic metre of the air at Montsouris there are on an average eighty bacteria.

They are most abundant in autumn, and least abundant in winter.

During dry weather the numbers increase, and a heavy rainfall reduces them.

It was also observed that winds from certain quarters, hospitals and slaughter-houses, and overcrowded dwellings, etc., float a great many bacteria to the observatory, but it is found that pure air from lofty districts contains scarcely any. Sunlight is most effective in destroying these organisms. Atmospheric oxygen is essential to the life of some bacteria, and Pasteur has termed these aerobic;[1] others again get their oxygen from the media in which they live, and these latter are designated anaerobic.[2]

Pure water is not exempt from the presence of bacteria. Bacteria are always found in larger numbers in water than in air.

As might be expected, the smallest number of these organisms occurs in condensed water vapour.

Taking the litre, which about equals $1\frac{3}{4}$ pint, it is found that the number of bacteria in a litre of condensed water vapour amounts to 900; the maximum, 80 millions per litre, occurs in sewer water that has been some time stagnant.

From the fact that if there is a proper flow of water the germs it contains never become dry enough to float in the air, an abundant flow of water in sewers is of prime importance, considering the danger attending the inhalation of these floating germs.

The sulphurous springs of the Pyrenees contain, in large numbers, a bacterium (Beggiatoa) which appears to accumulate sulphur in its cell, and is found especially in the floating scum termed glairine or barègene, a slimy substance found at Barèges, Aix-la-Chapelle, and elsewhere in hot springs. These hot springs serve as cultive fluids for the germs floating in the air. It is to the action of these fungi that the evolution of sulphuretted hydrogen from these springs has been attributed by Cohn.

[1] From the Greek *akros* extreme, and *bios* life.

[2] From the Greek *ana*, at the other extreme, literally, backward.

Certain bacteria often called Chromogenic[1] or colour-making, on account of the bright pigments they have accumulated, are found in water under certain conditions, and have given rise to the superstitious reports, that nearly every one has either read or heard, of 'blood-rain.'

It is more than fifty years since it was known that the red colour of stagnant pools in autumn is owing to a micro-organism, or minute fungus first described by Ehrenberg, and now known as belonging to the genus *Spirillum*.[2]

It has the property of rapidly changing from green to red. Now it might happen that a water-spout would draw up the bacteria-laden water of one of these stagnant ponds. On the water being re-discharged the red colouring pigments of the bacteria might very easily appear to the unreflecting as 'blood-rain.'

Snow is occasionally found to be coloured with a small fungus, Micrococcus;[3] but this is not the same as the much larger Protococcus of 'red snow.'

It might be supposed that spring-water, which percolates through the soil and is prized for its delicious coolness and freedom from all noxious compounds, would be free from bacteria. This, however, is not the case; for they are found in more or less abundance in spring-water taken from its source. Since the water is not, while beneath the surface, in contact with the air, it follows that it obtained from the soil the bacteria it contains.

Pasteur found that the germ of splenic fever (*Bacillus anthracis*)[4] abounded about the pits where diseased cattle had been buried.

The origin of most epidemic diseases has been referred to these deadly organisms from the soil; and hence the danger of drying marshes, and of river-beds that are becoming narrower, and of accumulations of dust and dirt generally.

[1] From the Greek *chromos* colour, and *genáu* to produce.

[2] Recent Latin from *spira*, that which is wound.

[3] From the Greek *mikros* small, *kokkos* a kernel.

[4] From Greek *anthrax*, literally, coal, in medicine a virulent abscess.

It would appear from the researches of M. Béchamp, that bacteria may remain dormant in the soil for many ages, and yet under certain conditions be capable of again becoming active. He found that a fresh piece of chalk taken from a quarry, precautions being taken to prevent the possibility of extrinsic germs coming in contact with it, gave rise to many of these germs. The length of time since the formation of chalk is incalculable. The same investigator also detected their presence in coal, but was unable to bring them back to life. Bacteria have also been found in the bricks of walls, and in association with the formation of saltpetre or nitrates of potassium and sodium in the soil.

*Food.*—These micro-organisms are always present in rancid butter, putrid cheese, tainted meat; and the yellowness and blueness of milk kept in vessels not hermetically[1] sealed, the disagreeable taste of some bread, and many other unhealthy conditions of food, are chiefly owing to the presence of bacteria. Blood-red stains on meat, paste, and other articles of food have been traced to the presence of a coloured micrococcus. The bitterness, ropiness, etc., of bad wine are owing to the presence of bacteria.

*Decomposition and Disease.*—Wherever decomposition and disease occur large numbers of bacteria are found in direct association therewith; though they do not appear to have any direct connection with decomposition. These bacteria are termed Saprophytic,[2] like fungi in general. Others of these organisms have, however, been proved to be the cause of pathological conditions both in men and animals; and the significance of this fact cannot be over-estimated as regards its bearing on the Germ Theory of disease. These bacteria which produce disease have been termed pathogenic.[3]

[1] From Hermes, the fabled inventor of alchemy, sealed to completely exclude air.

[2] From the Greek *sapros* rotten, and *phyton* a plant.

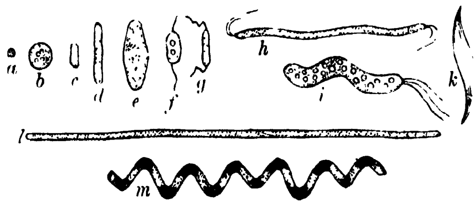
[3] From the Greek *pathos* suffering, and *genân* to produce or cause.

The presence of bacteria in the organism is not necessarily connected with disease, as many occur quite normally in healthy organisms.

The bacteria which abound wherever there is decaying matter have been termed, in contradistinction to the pathogenic bacteria, saprophytic, or, literally, those living on decayed plants, but really on all putrid organic matter.

### Form and Structure of Bacteria.

Four differently-shaped forms of the bacteria may be distinguished. The individual units may be spherical (*i.e.* shaped like a ball), or elliptical (*i.e.* a roundish body which measures more in one direction than in a direction at right angles to the longest measurement), or rod-like and spirally curved.




Different Forms of Bacteria (after Zopf)

*a*, Micrococcus; *b*, Macrococcus; *c*, Bacterium; *d*, Bacillus; *e*, Clostridium; *f*, *g*, *h*, *i*, Ciliated Phases; *k*, Spiromonas; *l*, Leptothrix; *m*, Spirillum.

Sir Joseph Lister and others have observed that a bacterium may pass from one form to another when subjected to different physiological conditions; viz., that a species spherical in its young stage may afterwards become elliptical or cylindrical, or that such a rod-like form as *Bacterium lactis*, which is the cause of the lactic acid fermentation in milk, or produces what is popularly known as 'sour milk,' may assume a thread-like or spiral form when sown in urine.

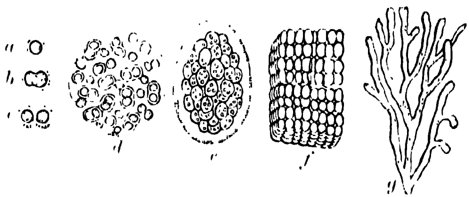
A single bacterium soon divides and forms a number of individuals, but the individuals produced by this division may be loosely united.

The berry-shaped micrococcus and the elliptical or

cylindrical bacteria always divide in one direction, and the two organisms thus produced may remain for a time united, or continue multiplying to form a huge colony imbedded in a jelly.

In *Bacillus*, *Leptothrix*,[1] and *Beggiatoa* the cells may assume the form of long cylinder-shaped threads, and in Vibrio Spirillum and Spirochaete,[2] the thread-like cells may be varied by the development of spiral or wavy curvatures.

The division in Sarcina[3] takes place in three planes. The division cross-wise increases the length, and at right angles to this the breadth, while division at right angles to the latter increases the thickness; the result is plainly the formation of a cubical clump or package; hence the name Sarcina.



MULTIPLICATION OF BACTERIA (after Zopf).

*a*, *b*, *c*, Division of Coccus (Crenothrix); *d*, round zooglœa of the same; *e*, oval zooglœa of Beggiatoa; *f*, cubical packets of Sarcina; *g*, ramified zooglœa of Cladothrix.

As in simple algæ, so here the results of the division are either isolated spheres, or longitudinal and sometimes branching filaments, or flat expansions; but always very minute structures.

*Structure.*—The small mass of protoplasm (the name given to the fundamental substance existing in all cells at certain stages of growth) which forms the unit or single bacterium is always surrounded by a membrane, which sometimes consists of the cellulose which forms the cell-wall of ordinary plants; but the cell-wall of a bac-

[1] From the Greek *leptos* fine, *thrix* (gen. *trichos*) thread.

[2] From the Latin *spira*, and Greek *chaite* horse-hair.

[3] From the Latin *sarcina* a package, load, etc.

terium more frequently consists of a peculiar albuminoid substance (*i.e.* a substance containing the elements which form ordinary albumen), termed mycoprotein (*i.e.* the fundamental material of fungi).

The membrane may be without colour, or brightly coloured, stiff or flexible, and always increases uniformly in thickness.

The protoplasm enclosed by the cell-wall consists of mycoprotein, and in addition may include granules of fatty matter, particles of uncombined sulphur, starch, granules, a brilliantly-coloured pigment in solution. No nucleus[1] has yet been observed.

Organs of locomotion in the form of delicate lashes or cilia are present at some stage or other, except when the bacteria form long filaments. The lashes or cilia are situated on the ends of the bacteria. These locomotor organs have been most frequently observed in the young swarm spores, and they vary in number from one to four. In the full-grown forms they are supposed to arise for the purpose of bringing the bacteria to the surface of the media in which they live when the protoplasm is in need of oxygen, or to some position in the media where oxygen is more abundant.

*Life-History.*—By life-history is meant the various stages through which an organism passes from its infancy to its adult period of existence. The life-history of bacteria may be conveniently divided into three important periods or phases; (1) increase in size and changes of form, (2) reproduction, (3) the assumption of the resting form known as zooglœa.[2]

(1) Increase in size and modification of form. If the bacteria are supplied with sufficient nutrition the individuals increase in size, and division and change of form then take place. The small spherical cocci become rod-like or cylindrical in shape, and the minute rods

[1] From the Latin *nucleus* kernel, or the hardest part.

[2] From the Greek *zoon* animal, and *gloia* glue, or *gloios* sticky.

divide, rapidly assuming the form of filaments from having ranged themselves in rows. These filaments are of course composed of individual bacteria, though their original distinctness is lost.

The kind and quantity of nutrition present have often an effect on the form of the separate rods as well as on the composite filaments, and both may become more or less spirally curved. Many forms were originally straight rods, and their life-history shows that these forms, whether they appear to be so or not, are aggregations of many cells. The technical term for this modification of the form is Pleomorphism.[1]

It has been observed that the longest chain of bacterium units never remains quite uniform throughout; in fact, all are not quite similar, but many variations occur. The ends of the chain may become enlarged, or at different parts of the chain individual masses may greatly exceed their neighbours in size. The same conditions are observed to occur amongst the filamentous algæ.

*Reproduction.*—Reproduction will now be briefly described as it occurs amongst bacteria.

It is believed that the more complete the degree of parasitism[2] among fungi, the more probable is the absence of what is termed sexual reproduction; or the production of new individuals by the union or contact of spores produced in special receptacles.

The multiplication of bacteria is an entirely asexual process. In certain plants of a higher order new individuals are frequently produced by division; but after a longer or shorter period, sexual reproduction intervenes.

It is supposed that the media in which bacteria live may, owing to their stimulating character, be regarded as a substitute for the stimulus to division usually supplied in other cases by fertilisation; the excessive smallness of

[1] From the Greek *pleon* more than, *morphē* form.

[2] *Para* beside, *sitos* food.

bacteria may be, and very likely is, due to the absence of sexual reproduction.

The process of multiplication is solely that of division. The coccus or rod-like form becomes slightly lengthened, a double partition wall grows in the middle, and two new or daughter cells are thus formed. . If the different cells formed in this way remain united, the result will be the formation of filaments. When the division takes place in more than one direction, plates are formed as in *Bacterium merismopedioides*, or in packets, as in *Sarcina ventriculi*, or in discs, as in *Crenothrix*.[1] In addition to this external and successive division, there is another process frequently seen in which division takes place in a less definite manner.

Spiral or other forms have been observed to divide rapidly into fragments, either externally without previous internal division or at first internally.

The flexible filament is ruptured in the middle and more passive part, and the two halves again divide, and so on. The detached fragments again grow to an adult size.

Besides these methods of purely vegetative reproduction, bacteria are also reproduced by means of special cells, viz., spores. This, however, is not a case of sexual reproduction, but a special case of internal division. The cell-contents contract, become closely aggregated and surrounded by a special wall or membrane.

This process has been observed in cocci, rods, and the spiral form.

In *Clostridium butyricum*, which causes butyric acid fermentation, the cells which form spores are differentiated from the others before the formation of spores takes place. These spores are formed when these organisms are insufficiently nourished. When the spores are liberated they germinate and become developed into full-grown forms. Finally, Zooglœa are formed. When bacteria are allowed to grow undisturbed, flakes or clumps of a jelly-like substance make their appearance. These were once

[1] *Crena* notch, *thrix* hair.

supposed to be quite distinct forms and were named zooglœa, but they are now known to be a phase in the life-history. These jelly-like clumps are frequently conspicuous both in size and colour. *Clostridium polymyxa*[1] may exceed an inch in width, and the 'frog spawn,' zooglœa, frequently found in beetroot juice, from which sugar is obtained, may be found as large as a foot across. These zooglœa consist of an innumerable assemblage of bacteria forming colonies, and are imbedded in a gelatinous substance.

These colonies result from an aggregation of resting spores which may arise from one or more mother cells; and the gelatinous substances in which they are imbedded originate from the thickening and gelatinisation of the cell-membranes of the bacteria forming the colonies. The thickening and gelatinisation of cell-membranes are not confined to bacteria, but are exhibited in other organisms.

## Classification of Bacteria.

Owing to the difficulties connected with the study of these minute organisms any classification attempted must as yet be merely provisional. Since this is the case even as regards flowering plants, which obviously have been much longer studied than these minute fungi, the fact that no completely satisfactory classification has yet been elaborated can be a matter of no surprise. There are numerous forms differing very little in points of structure, and the life-history of many genera is still incompletely known; besides, the same species may assume different forms under varied conditions; and other forms, which seem to be exactly alike, possess important physiological differences. Owing to these facts it will be seen that only a tentative classification is yet possible.

As far back as 1838—not a very long period in the

[1] *Polys* many, and *myxa* the curved part of a lamp.

history of a science—Ehrenberg distinguished four genera of bacteria. (1) *Bacterium*, straight and rigid; (2) *Vibrio*, snake-like and flexible; (3) *Spirillum*, spiral and rigid; (4) *Spirochæte*, spiral and flexible; but Dujardin united the two last into one genus. Cohn, who has greatly advanced the science of bacteriology, arranged the bacteria into four tribes. (1) Sphærobacteria, globules (micrococcus); (2) Microbacteria, short rods (*Bacterium*); (3) Desmobacteria, long rods (*Bacillus* and *Vibrio*); and (4) Spirobacteria, spirals (*Spirochæte* and *Spirillum*). This was the accepted classification for a few years, but has, on further knowledge of the life-history of bacteria, been abandoned.

Sir Joseph Lister in 1873 first gave good reasons for believing in the existence of pleomorphism (*i.e.* more than one form) in these organisms. He proved that certain forms, referred to distinct genera, were merely phases in the life-history of the same individual. Young and full-grown stages had been erroneously supposed to be different individuals, and forms and habits which were only temporary had been regarded as fundamental and fixed. Mistakes of this kind can only be avoided after the life-history of the individuals is completely known. What had been stated by Sir J. Lister was soon after completely verified by Professor Ray Lankester. Forms which Cohn had separated into distinct genera were shown to be successive chapters in the life-history of one individual.

Billroth (1874), Klebs (1875), Nägeli (1877), and others, but most of all Zopf, have clearly established the presence of pleomorphism, and have conclusively shown that whatever the final classification may be, it must be founded not on the mere form, but on the whole round of the life-history, and the whole of the variations in form which may in some cases be owing to the character of the media in which the bacteria live.

In classifying such lowly organisms as bacteria, where the field for the comparison of differences of structure is necessarily limited, the reproductive and vegetative phases

ought to be specially taken into account. It has, however, been shown that the range of vegetative modification is very limited in bacteria, and this holds true in regard to the reproductive processes as far as they are at present known.

It has been suggested by De Barry, that the bacteria may be grouped into those which form spores (endospores) and into those which become divided into segments, which are the equivalents of spores, but are not like endospores formed internally. The latter kind of spores he named arthrospores.[1] When the knowledge of the various reproductive processes is more advanced, the classification will be more fully elaborated.

Recent researches in fungi and algæ, which differ in this, that the algæ contain chlorophyll, and the fungi are quite devoid of chlorophyll, make still clearer the remarkably close correspondence both in structure and life-history between different groups in these two classes of plants.

In accordance with the tendency to limit the numerous classes to as few original types as are consistent with known facts, it has been suggested that the algæ and fungi should not be considered as separate branches in the genealogical tree. The various sub-divisions of the fungi ought according to this to be regarded as the representatives of parallel sub-divisions among the algæ, differing only from the algæ in being devoid of chlorophyll. This is specially to be borne in mind in regard to bacteria.

It is to be observed that some of the generic titles have come to be used in very various, and ambiguous ways. This is especially the case in regard to *Bacterium* and *Vibrio*,' which have been used so widely and ambiguously that some authorities would suppress them altogether as incapable of affording accurate generic designations.

Zopf's classification is now usually adopted. It of course is liable to be superseded as the knowledge of bacteria becomes extended.

[1] From the Greek *arthron* a joint, and *spora* seed.

Zopf distinguishes four groups:—1. Coccaceæ; 2. Bacteriaceæ; 3. Leptotricheæ; 4. Cladotricheæ.[1]

(1) *Coccaceæ*, only cocci, singly or in contact.

(2) *Bacteriaceæ*, for the most part with cocci, and also rods straight or bent and thread forms, which may be either straight or spiral, but are differentiated into a base and apex.

(3) *Leptotricheæ*,[2] cocci or thread-like forms with distinctive endings.

(4) *Cladotricheæ*, cocci, rods, threads and spirals.

1. In the first group, *Coccaceæ*, Streptococcus[3] is a genus with numerous species, some of which are associated with diseases in man and other animals; for example, with diphtheria, yellow fever, foot-and-mouth disease, others merely living on the results of pathological processes, and some having no connection with diseases of any kind. Packages of Sarcina are found forming coloured patches in various situations. Micrococcus has been seen in cases of measles, scarlatina, whooping-cough, typhus, and other diseases, but whether they cause these diseases or are merely in harmless association has not yet been clearly ascertained. Hydrophobia is doubtless due to the presence of a micro-organism, and micrococcus has been observed in this connection. The system of cure adopted by Pasteur is founded on the assumption of a causal connection. Many of the micrococci would appear to be merely saprophytic, or living in the media of waste products without being in any way associated with disease in the way of cause and effect.

2. *Bacteriaceæ*.—Species of bacterium have been found associated with lung disease, diphtheria, etc., other species cause fowl cholera, and other diseases of animals, and a large number have been observed forming no causal connection with any kind of disease.

*Bacterium prodigiosum* forms blood-red zooglœa, and may occur in bread, paste, milk, etc. 'Blood-rain' is coloured

[1] From the Greek *clados* a shoot, and *thrix* hair.

[2] From the Greek *leptos* fine, and *thrix*, *trichos* hair.

[3] From the Greek *streptos* twisted.

owing to its presence. This fungus was so prevalent in Paris in 1843 that it caused a sort of bread plague, especially in the military bakehouses.

*Bacterium aceti* has the power of oxidising alcohol in wine and other juices extracted from fruit. The alcohol is changed into acetic acid or vinegar.

*Bacterium termo* (Latin, a limit), which is nearly everywhere present, has been discovered to be only a phase in the life-history of many different forms.

Relapsing fever is said to be caused by a species of Spirillum; and Koch ten years ago discovered another form, *Comma bacillus* (this is really not a bacillus, but a fragment of *Vibrio*), which has been found in association with the Asiatic cholera.

The 'frog-spawn fungus' (*Leuconostoc mesenteroides*) sometimes spoils the beet-root juice and molasses in sugar factories.

*Bacillus* is a large genus with numerous species, which are most deadly enemies of man. Leprosy, typhoid fever, splenic fever, glanders, swine fever, lupus, and consumption are due to different species of bacillus.

The researches of Koch, to which further reference will be made, surpass in popular interest any other of a similar character. These have reference to the *Bacillus tuberculosis*.

The bacillus of blue milk, of hay infusion, and *Bacillus septicus* of fluids containing putrid albumen, are examples in association with disease. The disease of cattle known as 'black leg' or 'quarter evil' is owing to the presence of a species of *Clostridium*.

3. *Leptotricheæ*.—A species of Crenothrix has been known to occur in so great abundance as to stop up narrow water-pipes.

*Beggiatoa* is found in abundance under various forms in sulphur springs, in sea-water, and on the surface of marshes. The best-known species is of a peach-blossom, red colour.

*Leptothrix buccalis* is supposed to be associated with decay of teeth and is found in the mouth.

4. *Cladotricheæ* is the last group of bacteria. A species of this group noted for possessing false branches is more abundant in water containing organic matter than any other species belonging to the bacteria.

Little more than mere reference can be made to the vast group of these organisms. As has been said, their classification is in a transition state. In reference to the association of *Comma bacillus* with Asiatic cholera Koch claims nothing beyond the fact that the comma bacillus—which has been stated not to be a bacillus at all, but only a segment of a vibrio—is invariably present in cholera evacuations, and has been met with in wells polluted by them. We know that Koch, after he had neutralised the gastric juice of guinea pigs by alkalies, and administered opium to stop the motion of their bowels, introduced the Comma bacillus into their stomach. As almost a matter of course the pigs died, and the bacillus was found in their alimentary canal. It would certainly not be logical to assert that they died from the effect produced by the Comma bacillus, but that death was the result of the method of conducting the experiment; for Klein asserts that other bacilli introduced in the same way produced death.

It is known that Koch's cholera germ has been found in the saliva of perfectly robust and healthy persons, and water containing cholera evacuations charged with Koch's germ has been drunk with perfect impunity.

The following account of methods of research is taken from J. A. Thomson's article on Bacteria in Chambers's *Encyclopædia*, from which most of the other facts in connection with bacteria have been taken:—

*Methods of Research.*—'Besides the usual apparatus of any well-equipped laboratory for the study of minute structures and organisms, a number of special appliances are required for the successful investigation of bacteria. Thus, since the intrusion of germs, other than those which are the specific object of research, is a constant danger, there must be some means of sterilising the tubes, tools, machinery,

etc. This is generally done by means of a steam or hot-air steriliser, in which the extrinsic germs are killed off.

'Incubators are also used for the purpose of cultivation.

'The bacteria, obtained in endless ways, may be examined as they are, or stained with reagents to bring out the individual structures (acids, such as osmic acid, and alcohols, aniline, and all other chemical compounds used for bringing out the structure of animal or vegetable tissues, and also of micro-organisms, are termed reagents); or, since the life-history is all-important, they may be left to grow and watched at their successive stages. They used to be left in some sterilised fluid, such as broth, blood-serum, urine, milk, or Pasteur's fluid, and allowed to grow in test tubes or other vessels plugged with cotton wool. It is, however, exceedingly difficult to get a perfectly pure fluid medium, nor was it possible in such cases to isolate the different kinds of bacteria that might be present. In view of this Koch has recently introduced the method of cultivation on sterile solid media. Sterile nutrient gelatine, or some such substance, is liquefied in a tube and inoculated with the bacteria in question. These are distributed through the fluid, which is then poured out on a plate of glass and left to solidify. The various bacteria can no longer move about and mingle with one another, but are fixed to one spot where they develop. The resulting fixed colonies can thus be studied without confusion. Slices of sterilised potatoes are also frequently used as solid media for the cultivation of bacteria. Finally, to elucidate the relation of a micro-organism to a given disease, it is necessary not only to have obtained it from an organism suffering from the same disease, but it is imperative that some of a pure cultivation be introduced into a healthy organism to see whether it does not cause the disease. The introduction may be brought about by inhalation, or along with the food, or by injection in some form or other.'

At the beginning of the present year (1891) it was

asserted that Dr. Koch had succeeded in discovering a cure for consumption. The excitement caused by this announcement was intensified by the reports in the daily papers of wonderful cures. The method was to inject some of Koch's lymph under the skin of the patient.

The lymph is prepared by dissolving the bacillus. Dr. Koch himself made no claim to have done more than discover a possible remedy for incipient stages of this fell disease, and the consequent disappointment that has followed the high hopes then entertained is not to be attributed to any extravagant claims put forth by that eminent bacteriologist. Undoubtedly Koch's discovery is of great value, and the impetus given to researches in this direction may be productive of incalculable benefit to mankind.

Those who desire a full account of bacteria in connection with disease should read Dr. Woodhead's recently published most interesting volume on bacteria, which contains much valuable matter with copious illustrations. The sketch given here is merely intended to draw the attention of some readers to a subject of most vital and even pathetic interest.

# GLOSSARY AND INDEX

# GLOSSARY

**Absorption.**—Applied to those rays of light which, when they fall on a body, are swallowed up. From Latin *ab*, from, and *sorbeo*, I suck in.

**Acanthaceæ.** — A natural order of plants. (Greek *akanthos*, Latin *acanthus*, the plant *brank-ursine*, *bear's-breech*, *bear's-foot*.)

**Alcohol.**—Pure spirit. Derived from Arabic *alkohl*, powder of antimony used for blackening the eyelashes. The name was afterwards applied, on account of the fineness of this powder, to highly rectified spirits, a signification unknown in Arabia.

**Aldebaran.**—A star of the first magnitude situated in the eye of the constellation Taurus. From the Arabic *Al-dabaran*, 'the following,' since it follows the Pleiades.

**Algæ.**—(Latin, plural of *Alga*, seaweed.) A class of plant of which seaweed is the most familiar variety.

**Alkaloid.**—(*Alkali* and Greek *eidos*, form.) A vegetable principle possessing the properties of certain salts.

**Aluminium.** —(Low Latin *alumina*, Latin *alumen*, alum.) One of the lightest of the primary elements present in clay, slate, and some other minerals.

**Ammonia.**—A gaseous substance with a very pungent smell, obtained from sal ammoniac. So named from the Temple of Jupiter *Ammon*, near which it was first obtained.

**Anthers.**—(Greek *anthēros*, blooming.) Are the tops of the stamens of flowers in which the pollen is produced.

**Anti-cyclone.**—The name applied to a system of winds circulating round a region of high pressure; the direction of motion being opposite to that of the cyclone. Derived from Greek *anti*, against, and *kyklos*, a circle.

**Antimony.** — (From the Arabic.) A brittle bluish-white coloured metal possessing a flaky crystalline texture.

**Archæopteryx.** — An extinct bird, reptilian in structure. (Greek *archaios*, ancient, and *pteryx*, wing.)

**Atom.**—The smallest portion of a chemical element which can exist in the uncombined state.

**Atrophied.**—(Greek *a*, without, *trophē*, nourishment.) Arrested in development at an early stage of existence.

**Autumnal.**—Relating to the autumn. Applied to the equinox which occurs about 21st September. Derived from Latin *autumnus*. *See* **Equinox**.

**Axillary.** - - (Latin *axilla*, armpit.) Situated in the angle between the upper side of a branch and a stem; in Botany termed the *axil*.

**Axis.**—(Latin.) In Botany, is that portion of the plant which bears the lateral members or appendages.

**Bacterium aceti.**—The bacterium of sour wine. (Latin *acetum*, anything sour, vinegar.)

**Bacterium lactis.**—The bacterium of milk. (Latin *lac*, milk.)

**Bacterium prodigiosum.**—*i.e.* the bacterium of portentous character; presaging disaster of some mysterious kind.

**Barometer.**—The instrument used for measuring the pressure of the atmosphere; derived from the Greek *baros*, weight, and *metron*, a measure.

**Biology.**—(Greek *bios*, life, and *logos*,

discourse.) The science which treats of life.

**Bipinnate.** — Doubly pinnate. *See* **Pinnate.**

**Bolometer.**—An instrument for measuring the heating effect of the different rays of the spectrum. Derived from Greek *bolis*, a missile, hence ray.

**Botany.**—(Greek *botanē*.) The science which treats of plants.

**Buccalis.**—A species of Leptothrix. (Latin *bucca*, the cheek when puffed out.)

**Butyricum.**—The specific name of a bacterium, belonging to the genus Clostridium. (Latin *būtȳrum*, butter.)

**Calcium.**—(Latin *calx*, lime.) A yellowish-white metal present in chalk, lime-stone, etc.

**Carbon.**—(Latin *carbo*, *carbonis*, coal.) An elementary substance characteristic of animal organisms and plants.

**Carbonic Acid.**—A gas whose constituents are carbon and oxygen, and chemical formula $Co_2$.

**Carnivora.**—(Latin *caro*, flesh, and *voro*, I eat.) The order of animals which live on flesh.

**Carnivorous.**—Flesh-eating. *See* **Carnivora.**

**Cellular.**—(Latin *cella*, a storeroom.) Consisting of or containing cells.

**Cellulose.**—The substance secreted by living protoplasm of which its cell-membranes are composed.

**Chlorine.**—(Greek *chlōros*, pale green.) A noxious gas of a yellowish-green colour, much used as a bleaching and disinfecting agent.

**Chlorophyll.**—(Greek *chlōros*, pale green, and *phyllon*, a leaf.) The green colouring matter of plants, consisting of minute granules in the cells.

**Chromates.**—Salts of the oxy-acid formed by the combination of oxygen with the metal chromium, *i.e.* chromic acid.

**Chromosphere.**—The layer of gas supposed to surround the surface of the sun, constituting his atmosphere. From the Greek *chroma*, colour, and Latin *sphera*, a sphere.

**Cladobates.**—An insect-eating mammal. (Gr. *klados*, young shoot, an animal that walks on branches.)

**Clostridium.**—A genus of schizomycetes. (Closter, son of Arachne, inventor of the spindle, spindle-shaped.)

**Cohesion, attraction of.**—The force which exists between the molecules of bodies, either of attraction or repulsion.

**Colour-blindness.**—A defect in vision, arising from inability to perceive certain colours.

**Comet.**—A member of the solar system moving in an eccentric orbit. From the Greek *kometes*, long-haired, in allusion to its tail.

**Complementary Colour.**—The colour which, when combined with the remaining colours of the spectrum, gives white light.

**Compositæ.**—A natural order of plants including the daisy, etc. (Lat. *compositus*, compound, because the flowers of this large order are compound, each capitulum or small head containing numerous florets.)

**Concave.**—An object is said to be concave, when it has a surface hollowed in a curved line, as the interior of a section of a globe, or spherical body.

**Concave Lens.**—A lens bounded by one or more concave surfaces.

**Conduction.**—(Latin *con*, together, and *duco*, *ductum*, I lead.) Transmission by means of a conductor.

**Conifer.**—(*Cone*, and Latin *fero*, I bear.) The name of an order of trees, including pine and fir, in which the fruit is cone-shaped, or resembling a sugar-loaf.

**Conservation of Energy.**—Means that changes of energy from one form to another always take place subject to the law that the total amount of energy remains constant.

**Convection.** — (Latin *convectio*, from *conveho*.) The act of carrying or bringing together.

**Convex.**—An object is said to be convex when its surface is raised in a

curved line as the exterior of a globe or ball.

**Convex Lens.**—A lens bounded by one or more convex surfaces.

**Corona.**—The luminous appearance which surrounds the dark body of the moon during a total solar eclipse.

**Corpuscles.** — (Latin *corpusculum*, diminutive of *corpus*, a body.) Minute particles or bodies.

**Cretaceous.**—(Latin *cretaceus*, *creta*, Cretan earth, chalk.) Composed of or like chalk. In Geology the name given to the uppermost formation of the secondary period.

**Cryptogams.**—(Greek *kryptos*, hidden, and *gamos*, marriage.) A class of flowerless plants, which have their organs of fructification concealed or indistinct, as mosses, ferns, etc.

**Crystal.**—(Greek *krystallos*, clear ice.) In chemistry is a portion of matter which, by the action of certain molecular forces, assumes a definite geometrical form with plane faces.

**Cultive Fluid.**—A fluid in which bacteria may be cultivated.

**Cuticle.**—(Latin *cuticula*, dim. of *cutis*, skin.) In Botany is the thin vesicular membrane of plants.

**Cyclone.**—A violent storm; so named from the fact that the wind has a rotatory motion. Derivation, Greek *kyklos*, a circle.

**Cyperaceæ.**—A natural order of plants including the sedges. (Lat. *cyperos*, a kind of sedge.)

**Daughter Cells.**—Cells formed by a division of a single cell, termed the mother.

**Deciduous.**—(Latin *deciduus*, *decido*, I fall off.) Plants which lose their leaves once a year are so called.

**Dentine.**—(Latin *dens*, a tooth.) The substance of which a tooth is formed, under the enamel.

**Denudation.**—(Latin *denudo*, I lay bare.) The act of making bare or naked; a stripping off.

**Desmidiæ** (Desmids.)—A group of conjugate or united algæ of a bright green colour.

**Desmo-bacteria.** — One of Cohn's tribes of bacteria in his classification. (Gr. *desmos*, ligature, or bond.)

**Desmodium-gyrans.**—The telegraph plant of India belonging to the natural order Leguminosæ. (Gr. *desmos*, ligature, or bond; Lat. *gyrans*, wheeling round).

**Diathermanous.**—An attribute applied to any substance which does not absorb heat-rays when passing through it; the temperature of the substance being thereby unaffected. (Gr. *dia*, through, and *thermos*, heat.)

**Diatomaceæ.**—(Greek *diatomos*, cut in two.) A group of algæ of a brownish-yellow colour, so called from their increase by division longitudinally.

**Dichroic Vision.**—The perception of two colours. From the Greek *dichroos*, two-coloured (*dis*, two, and *chroa*, colour).

**Dioxide.**—(Greek *dis*, twice, and oxide.) An oxide containing one part of oxygen to two of a metal.

**Discrete.** — As applied to clouds, signifies that they are divided up, or are discontinuous.

**Dispersion.** — The scattering which white light undergoes when passed through a prism.

**Dissipation of Energy.** — The reducing of energy into a form no longer available for the performance of mechanical work.

**Dodder.** — (Danish.) A genus of parasitic plant, found on leguminous plants.

**Ductility.**—The property possessed by a solid body which enables it to be drawn into wire. From Latin *duco*, I lead.

**Ecliptic.** — The great circle in the heavens which represents the apparent yearly path of the sun round the earth.

**Edentata, Edentates.** — (Latin *edentatus*, toothless.) An order of mammalia characterised by the absence of all or some of their teeth.

**Elasticity.**—The property by means of

which bodies return more or less perfectly to their original shape when they have been altered in form by the action of some force.

**Embryo.**—(Greek *embryon*, the fruit of the womb before birth.) In Botany is the rudimentary plant within the seed.

**Embryology.** — The study of the development of the embryo.

**Emission Theory.**—The theory that light is due to the emission of luminous particles by the luminous body.

**Energy.**—The power of doing work.

**Epidermis.** — (Greek *epi*, upon, and *derma*, skin.) The outer or covering skin.

**Epiphytic.** — (Greek *epi*, upon, and *phyton*, a plant.) Pertaining to a species of plant (*epiphyte*) attached to trees, and deriving their nourishment from the decayed portions of bark.

**Equinoxes.**—The two periods of the year when the sun crosses the equator, making the days and nights of equal length; derived from Latin *aequus*, equal, and *nox*, night.

**Ether.**—The medium which is assumed to fill all space, and the vibrations of which constitute light.

**Euphorbiaceæ.** — A natural order of plants, including the spurges, and valuable for their secretions (named from Euphorbia, an African plant).

**Evaporation.** — (Latin *e*, off, *vapor*, vapour.) The act of passing gradually and imperceptibly into vapour or gas.

**Excretion.**—(Latin *excerno*, *excretum* I separate from.) The act or process of separating from or discharging; also that which is excreted.

**Extrinsic.**—Not belonging to, foreign to.

**Fauna.**—The whole of the animals of any given country or district. The word is derived from the mythical Fauns, formerly regarded as the protectors of wild animals.

**Flora.**—(Latin *flos*, a flower.) The whole of the plants growing in any given country or district.

**Fœtal.**—(Latin obsolete *feo*, I produce.) Pertaining to the fœtus or the young in the womb or egg.

**Foot-pound.**—A unit of energy or work, being equal to the work done in raising one pound avoirdupois against the force of gravity through a height of one foot.

**Fraunhofer's lines.**—The dark lines in the solar spectrum.

**Fructification.**—(Latin *fructus*, fruit, *facio*, I make.) The act of bearing or producing fruit; in Botany the word generally means all the parts that compose the flower or fruit.

**Fungi.** — Plural of *fungus* (Latin *fungus*, a mushroom). An order of plants of which mushrooms, toadstools, and mould, are the most common examples.

**Genera.**—Plural of *genus*.

**Genus.**—(Latin *genus*, birth, race.) A group consisting of a number of species possessing certain peculiar marks or characteristics in common.

**Germ Theory.** — This implies that disease is caused by living micro-organisms.

**Gold Chloride.**—A compound of the two elements gold and chlorine. *See* **Table of Chemical Elements**, p. 166.

**Gramineæ.**—A large and important natural order, including corn, wheat, grasses, etc. (Latin *grāmen*, grass.)

**Halo.**—A luminous circle round the sun or moon.

**Heliconidæ.**—A fanciful name given to a family of butterflies. (Greek *Helicon*, the abode of the Muses.)

**Hermetically sealed.**—So expressed when a glass tube is completely closed against the admission of air by having its ends fused. Derived from *Hermes*, the god of Science, and the fabled inventor of Chemistry.

**Hesperornis.** — The evening or western bird, an extinct species. (Greek *hesperos*, evening, and *ornis* bird.)

**Heterogeneous.** — (Greek *heteros*, other, *genos*, race.) Of another race or kind; the opposite of homogeneous.

**Homology.**—Correspondence of structure resulting from the development of similar embryonic parts.

**Horse-power.**—A power which can work at the rate of 33,000 foot-pounds per minute. *See* **Foot-pound.**

**Hydraulic press.**—A machine in which pressure is communicated to a piston by means of water, which is compressed. From Greek *hydor*, water.

**Hydrogen.** — (Greek *hydōr*, water, *gennaō*, to produce.) An elementary gaseous substance which united with oxygen produces water. *See* Table, p. 166.

**Hygienic.** — (Greek *hygieia*, health.) Pertaining to hygiene or the science which treats of the preservation of health.

**Hygrometry.**—The science of measuring the humidity of the air. The instruments used for this purpose are named *hygrometers*.

**Hyposulphite of Soda.**—A substance used in the *toning* and *fixing* of photographs. It is composed of the elements *sodium*, *sulphur*, and *oxygen* in certain proportions.

**Ichthyornis.**—An extinct bird. (Greek *ichthys*, fish, and *ornis*, bird.)

**Incubator.**—A machine by which eggs are hatched by artificial heat. Any contrivance for the cultivation of bacteria.

**Inflorescence.** — (Latin *inflorescens*, from *inflorescere*, to begin to blossom.) A beginning to flower or blossom: or the mode of flowering of different plants.

**Infusoria.**—Minute organisms, though much larger than bacteria, and occurring in water and other liquids. (Latin *infundare*, to pour into.)

**Inorganic.**—Not organic or possessing living organs. *See* **Organic.**

**Interference.**—A phenomenon observed in connection with light when waves proceeding from different centres of disturbance mix.

**Invertebrates.**—A class of animals without a backbone or spinal column. *See* **Vertebrates.**

**Iodine.**—(Greek *ioeides*, violet-coloured.) One of the chemical elements, so named from the violet colour of its vapour. *See* Table, p. 166.

**Isobars.**—A series of lines passing through all the points where the atmospheric pressure is the same, and where, therefore, the barometer will stand at the same height. Derived from Greek, *isos*, equal, and *baros*, weight.

**Isomorphous.**—(Greek *isos*, equal, and *morphē*, form.) Possessing the same crystalline form, but composed of different elements.

**Kinetic Energy.**—The energy which a body possesses in consequence of its motion. (Gr. *kineo*, I move.)

**Labiatæ.**—A natural order of plants, including dead-nettle. (Latin *labium*, a lip, named from the lip-shaped corolla.)

**Lamium album.**—White dead-nettle. (Latin *lamium*, dead-nettle, *albus*, white.)

**Latent Heat.**—The heat required to change a body from the solid to the liquid state, or from the liquid to the gaseous state.

**Lateral.** — (Latin *latus*, a side.) Proceeding from, or in the direction of one side.

**Latex.**—(Latin *latex*, a fluid.) The sap of plants after it has been elaborated in the leaves.

**Leguminosæ.** — A natural order of plants, including peas, beans, etc. (Latin *legumen*, pulse.)

**Leptalis.**—A genus of butterfly (Greek meaning delicate).

**Lens.**—A piece of glass or other transparent substance bounded by portions of two spherical surfaces.

**Leuconostoc.**—White nostoc. The nostoc is an alga which has been

popularly named from its appearance under certain circumstances 'fallen stars,' 'star-jelly,' also 'witches' butter.' (Greek *leukos*, white.)

**Litmus.**—A colouring matter obtained from lichens; used in chemistry for detecting the acidity of fluids.

**Magnesium.**—The metallic base of magnesia, a primary matter believed by the ancients to have the power like a magnet of attracting any substance when exposed to it. From *Magnesia*, in Asia Minor, where first found.

**Malleability.**—A property possessed by certain metals which enables them to be hammered into thin plates. From Latin *malleus*, a hammer.

**Mammæ.**—(Latin *mamma*, the breast.) In the highest animals the teats by which the young are nourished.

**Marsupials.**—(Latin *marsupium*, a pouch.) A class of animals which carry their young in a pouch, as the kangaroo.

**Maxillæ.**—(Latin, plural of *maxilla*, diminutive of *mala*, jaw.) The upper and lower jaws of animals and man.

**Maximum.**—(Latin, plural *maxima.*) The greatest quantity or degree.

**Mechanical Equivalent of Heat.**—The numerical relation between heat and work as ascertained from the number of units of work required to produce one unit of heat.

**Medium.**—(Plural *media.*) A Latin word meaning in the text, the substance in which bacteria live.

**Membrane.**—A thin skin or covering, *e.g.*, the covering which surrounds the fundamental substance composing the unit bacterium.

**Mercury Oxide.**—Compound of mercury and oxygen. *See* Table, p. 166.

**Merismopedioides.**—A species of a bacterium named from its manner of dividing. (Greek *merismos*, partition or dividing, *pedion*, flat surface, and *eidos*, shape.)

**Mesenteroides.**—A species of Leuconostoc. (Greek *mesos*, middle, and *enteron*, gut.)

**Metamorphosis.**—(Gk. *meta*, change, *morphē*, form.) Change of shape or form; the change which living beings undergo in the course of their growth.

**Meteor.**—A moving luminous body in the atmosphere. From the Greek *meteoros*.

**Meteorology.**—Means literally a discourse about meteors; but afterwards came to mean the science which treats of the atmosphere; derived from the Greek *meteora*, a meteor, and *logos*, a discourse.

**Minimum.**—(Latin, plural *minima.*) The least possible quantity.

**Molecule.**—The smallest part of a substance which can exist by itself, whether of a chemical element or a compound body.

**Molybdates.**—Salts of the oxy-acid formed by the combination of oxygen with the metal molybdenum, *i.e.* molybdic acid.

**Monochromatic Light.**—Light of one tint. From the Greek *monos*, single, and *chroma*, colour.

**Monsoon.**—A reversal of the prevailing wind which takes place twice a year in the Indian Ocean.

**Morphology.**—(Greek *morphē*, form, *logos*, a discourse.) The science which treats of the laws which regulate the forms assumed by animals and plants.

**Neap-tides.**—Tides that occur in the second and last quarters of the moon.

**Nebula.**—A faint cloud-like appearance seen among the stars, which the telescope shows to consist of a number of stars. (Latin *nebula*, diminutive of *nubes*, a cloud.)

**Neottia.**—A parasitic plant. (Greek meaning a nest.)

**Nicotine.**—The poisonous liquid forming the active principle of the tobacco plant. From Nicot, who introduced tobacco into France in 1560.

**Nitrogen.**—(Greek *nitron* and *gennaō*, to produce.) The gas forming nearly four-fifths of common air, so called

from its being an essential constituent of nitre. *See* Table, p. 166.

**Nutation.**—(Latin *nutans*, present participle of *nuto*, I nod.) In Botany the movement or turning of flowers towards the sun.

**Orchidaceæ.**—A natural order of plants containing the orchids. (Greek *orchis*, from which the orchids are derived owing to the form of their roots.)

**Organic.**—Consisting of or containing organs. *See* **Inorganic.**

**Organism.**—Applied in the text to any plant or animal, *e.g.* micro-organism or small organism. Anything possessing organs.

**Orion.**—One of the constellations. Originally a hunter, in Greek mythology.

**Ornithology.**—(Greek *ornis*, a bird, *logos*, a discourse.) The science of birds.

**Orobanche.**—A parasitic plant. (Latin and Greek supposed to be the dodder.)

**Osmotic.**—(Greek *ōsmos*, impulse.) Having the property of osmose or the tendency of fluids to mix or become equally diffused when in contact, even through an intervening membrane.

**Ovary.**—(Low Latin *ovarium*, from root of oval.) In Botany is the part of the pistil which contains the seed.

**Ovules** (Latin *ovum*, egg.) Of plants are the seeds in their earliest condition.

**Oxalic Acid.**—An acid composed of two parts of carbon, two of hydrogen, and four of oxygen.

**Oxidation.**—The changes which elementary or compound substances undergo when in combination with oxygen.

**Oxide of Uranium.**—A compound of oxygen and uranium. *See* **List of Chemical Elements**, p. 166.

**Oxygen.**—(Greek *oxys*, sharp acid, *gennaō*, to produce.) A gas without taste, colour, or smell, forming a constituent part of the air, etc. *See* Table, p. 166.

**Palæontology.**—(Gk. *palaios*, ancient, *onta*, existences, *logos*, discourse.) The science which treats of fossils.

**Permanganates.**—The prefix *per* in chemistry means *excess of*. Perchloric acid contains an atom of oxygen in excess of chloric acid. Permanganates contain twice as much oxygen relative to the base as manganates.

**Perennial.**—(Latin *per*, through, and *annus*, a year.) Lasting a whole year. Plants which last more than two years are called *Perennials*.

**Periodicity.**—A phenomenon which recurs after fixed intervals is said to be *periodic*, and this property is named *periodicity*.

**Perrutheniates.**—Compound of an oxy-acid formed by the combination of oxygen with the metal ruthenium.

**Petiole.**—(Latin *petiolus*, a little foot.) The foot-stalk of a leaf.

**Phanerogams.**—(Greek *phaneros*, open, *gamos*, marriage.) Plants with visible flowers containing stamens and pistils.

**Phosphorescence.**—Shining in the dark like phosphorus; derived from Greek *phōs*, light, and *phero*, I bring.

**Phosphorus.**—(Greek *phōs*, light, *pherein*, to bring.) A yellowish substance resembling wax, and luminous in the dark.

**Photography.**—The art of obtaining pictures by the action of light on chemically-prepared surfaces.

**Pieridæ.**—A fanciful name for a family of butterflies. (Greek *Pierides*, the Muses.)

**Pigment.**—A material for colouring.

**Pinnate.**—(Greek *pinna*, a feather.) Shaped like a feather, or feather-shaped.

**Pollen.**—(Greek *pallō*, to sift by shaking.) The male element in flowering plants, which by falling on the stigma causes the seed to swell or fecundate.

**Porosity.**—A term which implies that even in solid bodies the molecules are not in actual contact, but that between them pores or openings exist.

**Potassium.**—An alkaline metal of a bluish-white colour, and strong me-

tallic lustre, obtained by the reduction of its oxide, potash.

**Potential Energy.**—The energy which a body possesses in consequence of its position; or the energy due to the configuration of a system. Derived from Latin *potens*, possessing power.

**Precipitation.**—In Meteorology means the condensation and descent of the moisture contained in the atmosphere.

**Prism**—A wedge of glass of triangular shape. Derived from Latin *prisma*.

**Protozoa.**—(Greek *prōtos*, first, *zōon*, an animal.) A class forming the lowest division of animal life, possessing scarcely any distinctive organs.

**Protuberances (solar).**—Elevated portions of the chromosphere of the sun. *See* **Chromosphere.**

**Psychology.**—(Greek *psychē*, soul, *logos*, a discourse.) The science of mind and its faculties.

**Raceme.**—(Latin *racemus*, a bunch or cluster.) A flower cluster, as in the currant.

**Radiant Energy.**—Energy in the form of light and heat.

**Radiation.**—(Latin *radio*, *radius*, a beam or ray.) The diffusion of rays of light or heat.

**Reflection of Light.**—The bending back of a ray of light when it strikes a reflecting surface.

**Refraction of Light.**—The deviation which a ray of light undergoes in passing from one medium to another.

**Refrangibility.**—A term applied to a ray of light and said to be greater or less according to the position the ray occupies on the spectrum. Derived from Latin *re*, back, and *frango*, I break.

**Rubiaceæ.**—A natural order of plants, including madder. (Latin *rubia*, madder.)

**Saccate.**—(Latin *saccus*, a bag.) Pertaining to, or possessing, small sacs or bags for liquid.

**Satellite.**—The attendant of another planet. From *satelles*, an attendant.

**Self-luminous.**—Applied to a body which shines by its own light.

**Septicus.**—A species of bacillus. (Latin *septicus*, putrifying, septic.)

**Sessile.**—(Latin *sessilis*, dwarfed.) Leaves which grow directly from the stem, without a foot-stalk, are so termed.

**Solstice** (*Winter* and *Summer*.)—The two points on the ecliptic where the sun at these two seasons is at the greatest distance from the equator, and seems to be stationary. Derived from Latin *sol*, the sun, and *sisto*, to cause to stop. *See* **Ecliptic.**

**Spectroscope.**—The instrument used for viewing the spectrum.

**Spectrum.**—(Latin *specio*, I see.) The coloured image of any luminous body produced by the refraction of its light through a prism.

**Sphærobacteria.**—One of Cohn's tribes in his classification of bacteria. (Greek *sphaira*, a round body, ball.)

**Spring-tides.**—Tides that occur at, or soon after, the new moon and full moon.

**Stigma.**—(Latin, from Greek *stizein*, to prick.) The top of the pistil in flowering plants.

**Style.**—(Latin *stilus*, an upright pointed body.) The middle portion of a perfect pistil between the ovary and the stigma.

**Sulphuretted hydrogen.**—A gas composed of two atoms of hydrogen, and one atom of sulphur. Much used in chemical analyses, and possesses a characteristic smell. *See* Table, p. 166.

**Thermometer.**—An instrument for measuring temperature or the intensity of heat. Derived from the Greek *therme*, heat, and *metron*, a measure.

**Total reflection.**—When a ray of light travelling in a given medium reaches the surface of that medium, and instead of passing out of the medium is reflected internally, the phenomenon is called *total reflection.*

**Trade Winds.**—Winds near the torrid

zone which blow in a fixed direction for a certain time.

**Transparent bodies.**—Bodies which allow light to pass through them.

**Trichroic vision.**—The perception of three colours. From the Greek *trichroos*, three-coloured (*tris*, three, and *chroa*, colour.)

**Trilobate.**—(Greek *tri*, thrice, *lobos*, a lobe.) Having three lobes or divisions.

**Tropidorhynchus.**—The name of a bird, given owing to its keel-shaped bill. (Greek *tropis*, keel, and *rhynchos*, bill.)

**Tuberous.**—(Latin *tumeo*, I swell.) Plants whose roots are tubers or knobs, as potatoes, turnips, beets, and carrots.

**Turgidity.**—(Latin *turgidus*, from *turgeo*, I swell.) State of being swollen or distended beyond the natural size.

**Undulatory** or **Wave Theory.**—The theory that light is due to the undulations of an ethereal medium; derived from the Latin *unda*, a wave.

**Ungulates.**—(Latin *ungula*, a hoof.) A section of the class Mammalia consisting of those animals which have hoofs.

**Ventriculi.**—A species of the genus Sarcina (genitive case of Latin *Ventriculus*, belly, dim. from *venter*).

**Vernal.**—Relating to the spring. Applied to the equinox which happens about 21st March. Derived from Latin *ver*, spring. *See* **Equinox**.

**Vertebræ.**—(Plural of *vertebra*, from Latin *verto*, I turn.) The bones and joints forming the back-bone in man and animals.

**Vertebrates.**—The highest division of the animal kingdom, comprising all animals that have a backbone.

**Vibrio.**—A bacterium. (Latin *vibrare*, to quiver, move with a tremulous motion.)

**Volatile.** — (Latin *volatilis*, flying.) Liable to waste or disappear by evaporation.

**Whorl.**—An arrangement of leaves in a circle round the stem of a plant. Connected with the word whirl.

**Work, unit of.**—One pound raised vertically one foot against the force of gravity.

**Xanthophyll.** — One of the three constituents of Chlorophyll. *See* **Chlorophyll.**

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